JOURNAL of the AMERICAN SOCIETY *of* *NAVAL ENGINEERS* Inc.

November, 1959

Volume 71 Number 4

The CAPTAIN ROBERT B. MADDEN, U. S. N. *Issue*

Presidents of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

REAR ADMIRAL WILLIAM A. DOLAN, JR., U. S. NAVY

Past Presidents

1889-90 *Chief Engineer Nathan P. Towne, U. S. Navy*
1891 *Past Assistant Engineer G. W. Baird, U. S. Navy*
1892 *Chief Engineer David Smith, U. S. Navy*
1893-94 *Chief Engineer H. Webster, U. S. Navy*
1895 *Chief Engineer James H. Perry, U. S. Navy*
1896 *Chief Engineer E. D. Robie, U. S. Navy*
1897 *Chief Engineer David Smith, U. S. Navy*
1898-99 *Chief Engineer H. Webster, U. S. Navy*
1900 *Commander H. Webster, U. S. Navy*
1901-02 *Commander C. W. Rae, U. S. Navy*
1903 *Lieutenant Commander W. M. Parks, U. S. Navy*
1904 *Rear Admiral John D. Ford, U. S. Navy*
1905 *Commander A. F. Dixon, U. S. Navy*
1906 *Commander A. B. Canaga, U. S. Navy*
1907 *Commander B. C. Bryan, U. S. Navy*
1908 *Commander R. S. Griffin, U. S. Navy*
1909 *Rear Admiral John K. Barton, U. S. Navy*
1910-11 *Engineer-in-Chief H. I. Cone, U. S. Navy*
1912-13 *Captain R. S. Griffin, U. S. Navy*
1914 *Rear Admiral J. R. Edwards, U. S. Navy*
1915 *Captain S. S. Robison, U. S. Navy*
1916 *Captain C. W. Dyson, U. S. Navy*
1917-18 *Captain H. P. Norton, U. S. Navy*
1919 *Rear Admiral H. P. Norton, U. S. Navy*
1920 *Rear Admiral C. W. Dyson, U. S. Navy*
1921 **Captain A. J. Hepburn, U. S. Navy**
1922 *Rear Admiral C. W. Dyson, U. S. Navy*
1923-24 *Captain J. T. Tompkins, U. S. Navy*
1925 *Rear Admiral C. F. Hughes, U. S. Navy*
1926 *Rear Admiral M. M. Taylor, U. S. Navy*
1927 *Rear Admiral John Halligan, U. S. Navy*
1928 *Captain E. L. Bennett, U. S. Navy*
1929-30 *Rear Admiral H. E. Yarnell, U. S. Navy*
1931 **Rear Admiral S. M. Robinson, U. S. Navy**
1932 *Rear Admiral F. B. Upham, U. S. Navy*
1933 *Rear Admiral William A. Moffett, U. S. Navy*
1933 *Rear Admiral E. J. King, U. S. Navy*
1934-36 **Rear Admiral William H. Standley, U. S. Navy**
1937 **Rear Admiral Alfred W. Johnson, U. S. Navy**
1938 **Rear Admiral Harold G. Bowen, U. S. Navy**
1939 **Rear Admiral S. M. Robinson, U. S. Navy**
1940 **Rear Admiral Henry Williams, U. S. Navy**
1941 *Captain Claud A. Jones, U. S. Navy*
1942 **Rear Admiral Herbert S. Howard, U. S. Navy**
1943 *Rear Admiral J. J. Broshek, U. S. Navy*
1944 *Rear Admiral C. L. Brand, U. S. Navy*
1945 **Rear Admiral E. W. Mills, U. S. Navy**
1946 *Rear Admiral Harvey F. Johnson, U.S.C.G.*
1947 **Rear Admiral C. W. Styer, U. S. Navy**
1948 **Rear Admiral Roger W. Paine, U. S. Navy**
1948 *Rear Admiral Harvey F. Johnson, U.S.C.G., Ret.*
1949 **Rear Admiral T. A. Solberg, U. S. Navy**
1950 **Rear Admiral F. E. Haeberle, U. S. Navy**
1951 **Rear Admiral David H. Clark, U. S. Navy**
1951 **Rear Admiral Louis Dreller, U. S. Navy, Ret.**
1952 **Rear Admiral T. C. Lonnquest, U. S. Navy**
1953 **Rear Admiral Homer N. Wallin, U. S. Navy**
1954 **Rear Admiral Evander W. Sylvester, U. S. Navy**
1955 **Rear Admiral W. D. Leggett, Jr., U. S. Navy**
1955 **Rear Admiral F. R. Furth, U. S. Navy**
1956 **Rear Admiral Kenneth K. Cowart, U.S.C.G.**
1957 **Rear Admiral Albert G. Mumma, U. S. Navy**
1958 **Rear Admiral Lenoy V. Honsinger, U. S. Navy**

---

*Names in italics deceased

JOURNAL

of

The American Society of Naval Engineers, Inc.

PUBLISHED QUARTERLY

UNDER THE SUPERVISION OF THE COUNCIL

Rear Admiral WILLIAM A. DOLAN, JR., USN, President

Captain JAMIE ADAIR, USN

Commander R. S. BURPO, JR., USNR

Mr. HUGH E. CARLETON

Commander JOHN A. COIL, USN

Mr. GILBERT S. FRANKEL

Captain IVAN MONK, USN

Lt. Comdr. DONALD E. REDMON, USNR

Captain THOMAS W. ROGERS, USN

Rear Admiral E. H. THIELE, USCG

Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

SEVENTY-FIRST YEAR

VOLUME 71 NOVEMBER, 1959 NUMBER 4

Published Quarterly at Washington, D.C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D.C., and at Nashville, Tenn. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 3, 1918.

Subscription Rates for Non-Members

The subscription price of the JOURNAL, postpaid to points in the United States and possessions is $12.00. Single copies, $3.00. To other countries, $20.00. Single copies, $5.00. All subscriptions payable in advance.

Make checks, drafts and postal money orders payable to THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Advertising rates will be furnished on application.

Addresses will be changed at any time, but only upon notification. Immediate notice should be given of any delay in the receipt of the JOURNAL.

Address all communications for the Society to

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Suite 403, Continental Building
1012 14th Street, N.W.
Washington 5, D.C.

The American Society of Naval Engineers, Inc., has no official connection with the Navy Department.

TABLE of CONTENTS

PAGE

Secretary's Notes 583

The Costs and Risks of Engineering Progress
by CAPTAIN N. SONENSHEIN, U.S.N. 589

External Deposits and Corrosion in Boilers and Gas Turbines
Reprinted from *Mechanical Engineering,* June 1959 599

Hydrofoil Boats as a Means of Transportation
by HANS VON SCHERTEL; Translated by Dr. Ing S. F. Hoerner 603

Special Purpose Marine Propulsion Systems, Part II
by ROBERT TAGGART 615

A Program for the Development of an Improved Hydraulic Jet Propulsion Device
by ROBERT TAGGART 623

Machines for Precision Reduction Gears
Reprinted from *The Marine Engineer and Naval Architect,* April, May, June 1959 633

The Gay-Lussac Free Expansion Experiment
by DEAN J. H. POTTER 643

Some Engineering Aspects of High-Performance Aircraft
Reprinted from *The Chartered Mechanical Engineer,* June 1959 649

Thermoelectricity—A Ray From the Brighter Tomorrow
by LIEUTENANT (j.g.) JOHN C. COOPER, U.S.N. AND CAPTAIN NORBERT FRANKENBERGER, USN 657

Where Transistors Stand Today
Reprinted from *Engineering,* June 5, 1959 665

Basic Design Concepts
by ASSOCIATE PROFESSOR J. HARVEY EVANS 671

The Project Manager—His Role in Advanced Technology Industry
Reprinted from *Westinghouse Engineer*, July 1959 679

Interaction Between Single Screw Propellers and Twin Rudders Placed Symmetrically in the Screw Race
by PROFESSOR K. KAFALI 685

Lifting-Line Theory of the Submerged Hydrofoil of Finite Span, Part II
by PROFESSOR TETSUO NISHIYAMA 693
With Discussion by DR. B. L. SILVERSTEIN 700

Marine Engineering Notes from the Soviet Press
by COMMANDER BERNARD M. KASSELL, U.S.N. 703

Techniques and Practices in Recent Naval Steam Turbine Construction
by LIEUTENANT HAROLD L. YOUNG, U.S.N. 711

Water Injection: A New Protective System for Missile Magazines
by COMMANDER B. F. SEEGER, U.S.N. AND ROGER H. LAPP 719

Organic Reactor Eyed for Nuclear T-7
Reprinted from *Marine Engineering/Log*, August 1959 723

The Platinum Resistance Thermometer
Reprinted from *Platinum Metals Review*, July 1959 729

New Developments in the Welding of Aluminum
Reprinted from *The Welding Journal*, July 1959 735

DEPARTMENTS

Obituary—Rear Admiral Claude S. Gillette, U.S.N., Retired 745

Changes in Membership 746

Deaths 746

Association Notes 747

INDEX to ADVERTISERS

Name	Manufacturers of or Dealers in	Post Office Address	Page
A			
American Brass Co.	Engineering Service on Anaconda Metals	Waterbury, Conn.	xxii
American Engineering	Steering Gears, Windlasses, Winches	Philadelphia 37, Pa.	xviii
B			
Babcock & Wicox	Marine Boilers	Barberton, Ohio	iv
Bath Iron Works	Shipbuilders and Engineers	Bath, Maine	ii
Bethlehem Steel Co.: Shipbuilding Division	Steam Turbines, Propellers, Shafts, Evaporators, Shipbuilding and Repair	25 Broadway, New York, N.Y.	vi
Bird-Johnson	Controllable Pitch Propellers	South Walpole, Mass.	iii
Buffalo-Pumps, Division of Buffalo Forge	Pumps—Fans	490 Broadway, Buffalo 5, N.Y.	v
C			
Combustion Engineering Co.	Marine Steam Generators, Bent Tube and Straight Tube Boilers, Forced Circulation Boilers, Superheaters, Economizers and Air Heaters	200 Madison Ave., New York City, N.Y.	viii
Crane Co.	Valves and Fittings	Chicago 5, Ill.	xix
G			
Gibbs & Cox Inc.	Naval Architects and Engineers	New York, N.Y.	vii
Grinnell Co., Inc.	Fire Protection Systems	260 W. Exchange St., Providence 1, R.I.	i
I			
International Nickel Co.	Producers of Nickel	67 Wall St., New York, N.Y.	ix
J			
Johns-Manville	Insulation, Refractory Cements, Packings, Brake Linings, Asbestos Ebony for Switch and Panel Boards, Waterproofing, Transite Asbestos Sheets, Transite Pipe, Roofing and Shingles, Flooring Insulating Board Products	22 East 40th St., New York, N.Y.	xv
K			
Kingsbury Machine Works, Inc.	Thrust Bearings, Journal Bearings, Thrust Meters	Frankford, Philadelphia, Pa.	vii
L			
Leslie Co.	Regulators & Controllers	413-C Grant Avenue, Lyndhurst, N.J.	xxiv
M			
Moffitt, Lucian Q., Inc.	Cutless Bearings for Stern Tubes and Struts	Akron, Ohio	xv

Name	Manufacturers of or Dealers in	Post Office Address	Page
N			
Newport News Shipbuilding and Drydock Co.	Naval and Merchant Vessels	Newport News, Va.	xiv
R			
Radio Corporation of America	Radio Equipment	Camden, N.J.	xxi
Rosenblatt, M. & Son	Naval Architects, Marine Engineers	350 Broadway, New York, N.Y.	xv
S			
Sperry Piedmont Company (Division of Sperry Rand Corporation)	Radar, Loran, Gyro-Pilots, Gyro Compasses, Electric and Hydraulic Steering Equipments, Magnetic Compass Pilot, Rudder Angle Indicator, Naval Fire Control Instruments, Aircraft Gyropilots, Flight Instruments	Charlottesville, Va.	xxiii
Stromberg-Carlson Company	Electronics	Rochester, N.Y.	xvi
T			
Terry Steam Turbine Co.	Steam Turbines	Hartford, Conn.	xvii
W			
Westinghouse	Nuclear power plants, geared turbine propulsion systems, turbine and diesel electric propulsion systems, auxiliary turbine-generator units, mechanical drive turbines, forced draft blowers, heat transfer equipment, generator and distribution switchboards, circuit breakers, electrical instruments, transformers, auxiliary motors and control, ventilating equipment, nuclear instrumentation and control "canned" pumps and valves and decorative Micarta (R).	3 Gateway Center, Pittsburgh 30, Pa.	xii, xiii
Wheeler, C. H.	Steam Condensers, Pumps, Deck Machinery	19th & Lehigh, Philadelphia, Pa.	xx
Whittelsey, H. Newton	Naval Architects, and Marine Engineers	17 Battery Place, New York 4, N.Y.	xv
Worthington Corp.	Shipboard Equipment	Harrison, N. J.	x, xi

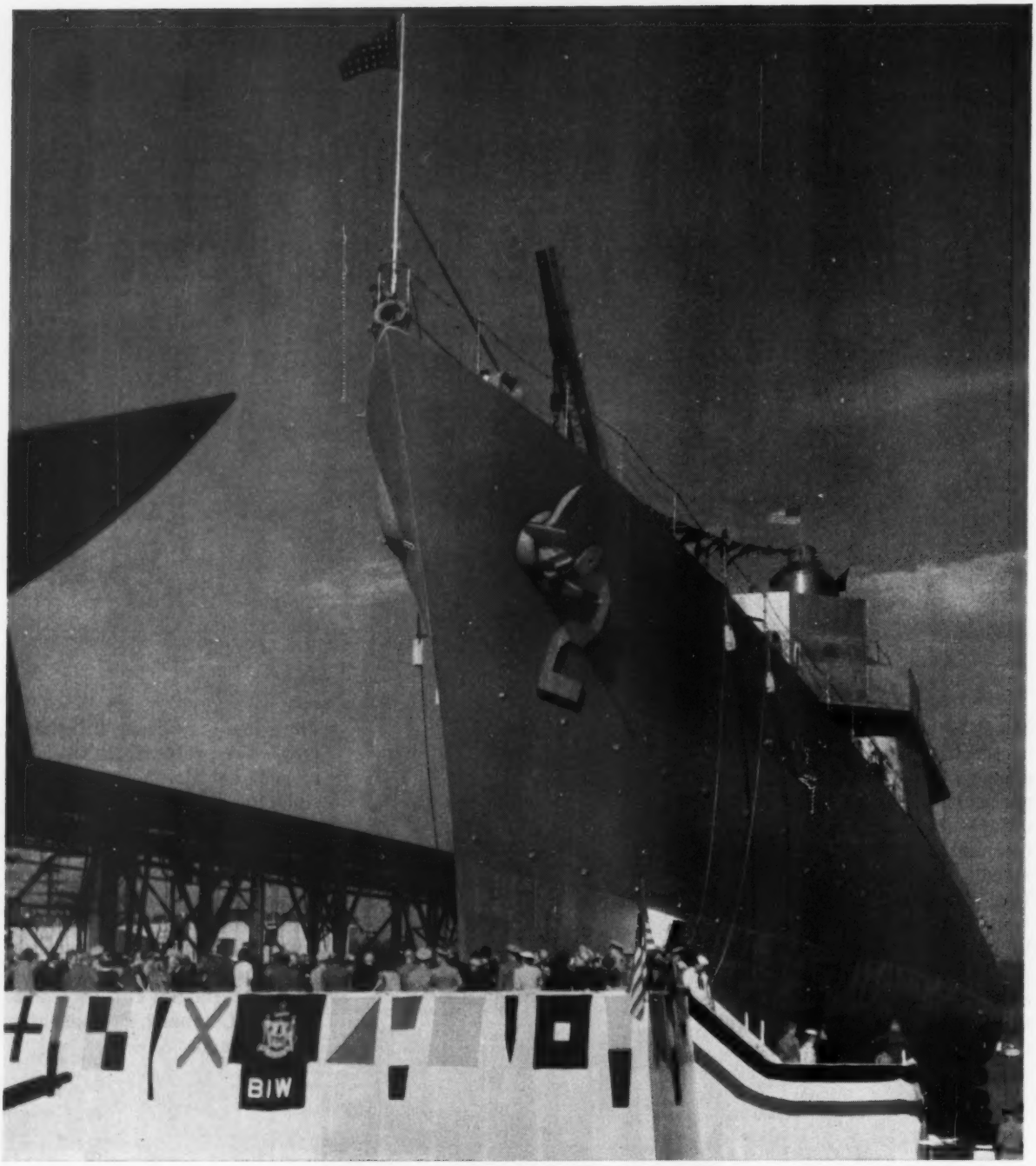
For Control of Accidentally Ignited Missiles ... Fire Detector-Water Injection Nozzle

Missiles are among the most destructive weapons in our fast-growing arsenal. Their storage, particularly aboard naval craft, creates critical problems. So Grinnell and the Navy collaborated on the development of this Fire Detector - Water Injection Nozzle. This device is actuated by shock waves should fire start in a missile booster. Then, almost instantaneously, the nozzle delivers a stream of water to control or extinguish the burning.

The same experience in solving tough fire problems is available to you. Let Grinnell be responsible for the fire protection on your next installation—whether it requires standard equipment, or special development work. Remember, Grinnell's specialty is fire protection . . . with a background of successful research, engineering, manufacturing and installation for 89 years. Grinnell Company, Providence 1, Rhode Island.

GRINNELL

Research, Engineering, Manufacturing and Installation of Fire Protection Systems since 1870



THE U.S.S.

CHARLES F. ADAMS (DDG-2)

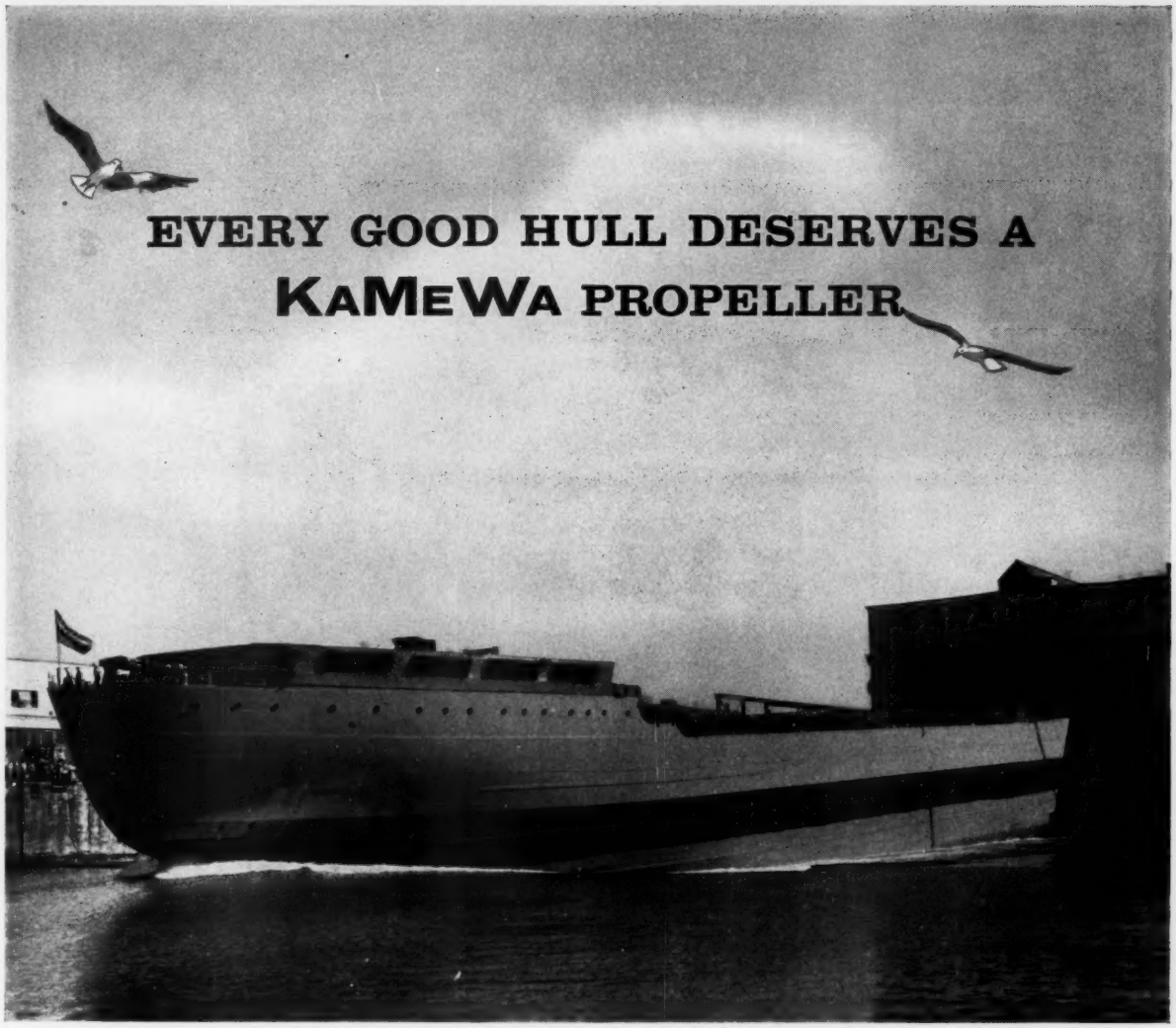
launched at Bath Sept. 8, 1959.

Lead ship of the Navy's first group of destroyers designed and built to carry guided missiles. The Adams and her 17 sister ships, now under construction here and in four other shipyards, will carry the Tartar Missile. These splendid new destroyers are 431 feet long, 47 feet in beam, and have a standard displacement in the light condition of 3370 tons.

BATH IRON WORKS

Shipbuilders & Engineers

BATH, MAINE



The M-V Avery C. Adams and her sister ship, M-V Alexander T. Wood, are the largest ocean-going dry-bulk carriers built in Canada. Designed by H. C. Downer Associates for deep-sea-Seaway-Great Lakes service, both are equipped with KaMeWa controllable pitch propellers.

Compared to the cost of a modern hull, propellers are a relatively insignificant item . . . yet many a ship is handicapped throughout its productive life by the limitations of fixed pitch propellers.

With KaMeWa controllable pitch propellers, you literally fit the propeller to the hull — not just for average operating conditions, but for any condition of sea, speed or load that will ever be encountered.

The result is more efficient horsepower utilization, lower operating cost, less time lost for engine repair and maintenance . . . in short, lower cost per ton-mile. In addition, KaMeWa greatly improves ship handling ability and promotes safety through better maneuverability.

May we send names and descriptions of typical KaMeWa installations and performance records of KaMeWa-equipped vessels in your field of operation? Write for complete information. Address Dept. NE Bird-Johnson Company, South Walpole, Massachusetts.

KAMEWA

Controllable Pitch
PROPELLERS.

Sales Office: 21 West St., New York 6, New York
In Canada: A. Johnson & Co., Ltd., 607 Shell Tower Bldg., Montreal 2
Pacific Coast: H. J. Wickert & Co., Inc., 770 Folsom St., San Francisco

Whose flag will fly on America's fourth coast?

At the head of the Great Lakes is the Duluth-Superior Harbor—the largest port served by the St. Lawrence Seaway. Of the first 19 lines to stake their claim to Great Lakes trade, *not one ship flies the American flag.*

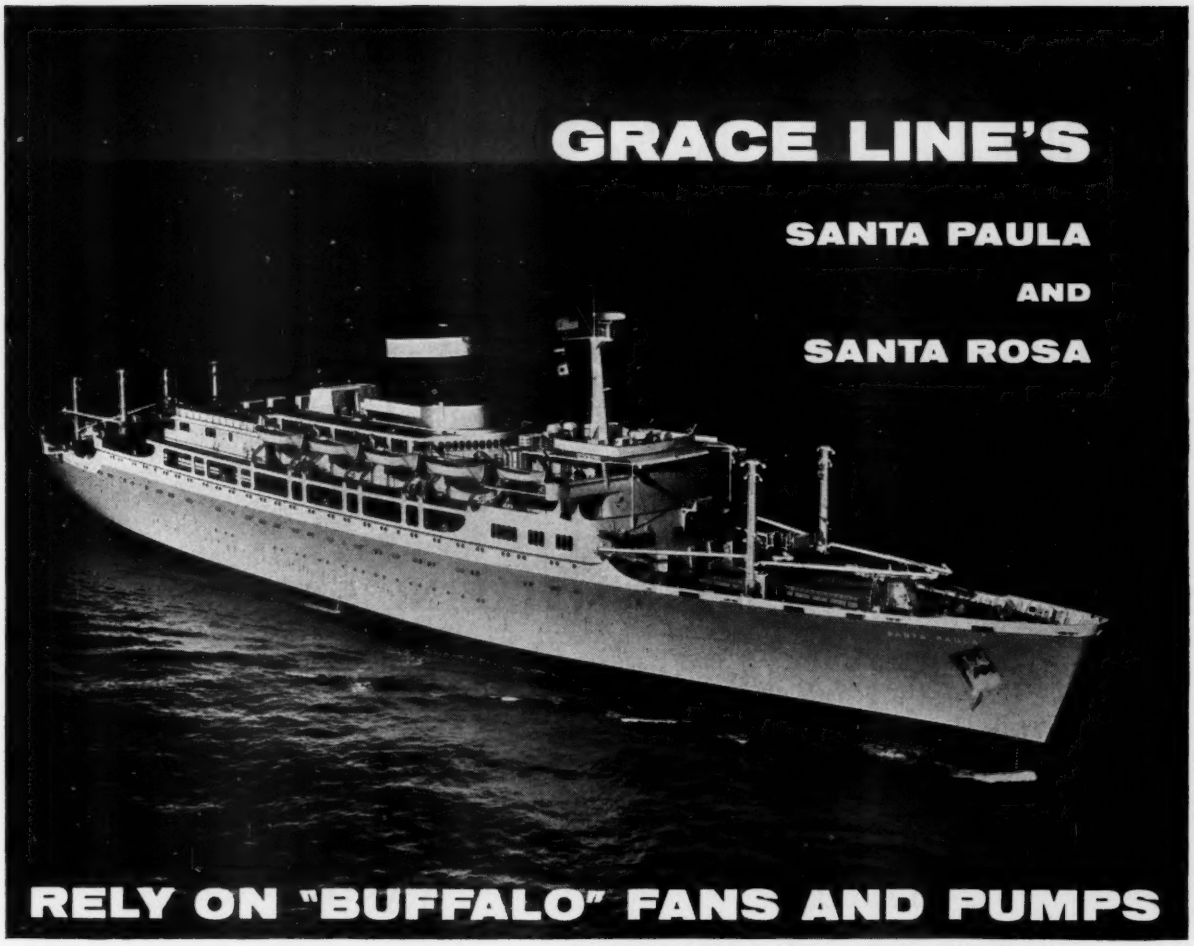
Completion of the great St. Lawrence Seaway means more thousands of tons of bulk cargo loaded at Lake ports now open to foreign trade. This opening of America's fourth coast gives the industrial middle west direct access to the markets and raw materials of the world.

For American industry to take full advantage of this new Seaway, it is vital to have a strong American Merchant Marine. We *must* have ships—American ships—to carry these cargoes that will help our country grow stronger. It is essential to our industrial and economic future!

The Babcock & Wilcox Company, Boiler Division, 161 East 42nd Street, New York 17, New York.

Since 1875, The Babcock & Wilcox Company has dedicated itself to a tradition of excellence in marine boiler design and construction.

M-407 B&W THE BABCOCK & WILCOX COMPANY
BOILER DIVISION



The Santa Paula and her sister ship Santa Rosa of the Grace Line were constructed by Newport News Shipbuilding and Dry Dock Co.

The Grace Line's Santa Paula and her sister ship, the Santa Rosa sail on weekly schedules from New York to the Caribbean. The 300 passengers on each ship are treated to the best. Complete air conditioning; play deck with largest outdoor swimming pool afloat; club; staterooms, all outside with private bath; Balcony Suites with verandas overlooking the sea; everything to guarantee passenger rest and recreation. Ports of call are Curacao, NWI; La Guaira, Venezuela; Aruba, NWI; Kingston, Jamaica; Nassau, Bahamas; and Port Everglades, Florida.

Contributing to the successful operation of each ship are 74 "Buffalo" Centrifugal Fans; 55 "Buffalo" Axial Type Fans; and 21 "Buffalo" Pumps. Engineered to give maximum performance, quiet operation and reliable low maintenance, "Buffalo" Fans and Pumps have been widely used for marine service for many years. The complete selection of fans offered is sure to include any standard or special applications you may have from ventilation to gland leak-off. "Buffalo" Pumps are available in standard, close-coupled or vertical styles in a wide range of capacities.

For reliability at sea, be sure to have "Buffalo" "Q" Factor* Equipment aboard ship.

**The "Q" Factor — the built-in Quality which provides trouble-free satisfaction and long life.*

BUFFALO FORGE COMPANY

Buffalo Pumps Division
535 Broadway, Buffalo, N.Y.
Canada Pumps Ltd., Kitchener, Ont.

MARINE DEPARTMENT: 711 WOODWARD BUILDING • WASHINGTON 5, D. C.

BETHLEHEM STEEL

Shipbuilding Division

NAVAL ARCHITECTS and MARINE ENGINEERS

Manufacturers of Marine Machinery and Special Products
Propellers *Fresh Water Distillers* *Steam Turbines*

SHIPBUILDING YARDS

QUINCY YARD
Quincy, Mass.

STATEN ISLAND YARD
Staten Island, N. Y.

SPARROWS POINT YARD
Sparrows Point, Md.

BEAUMONT YARD
Beaumont, Texas

SAN FRANCISCO YARD
San Francisco, Calif.

SHIP REPAIR YARDS

BOSTON HARBOR
Boston Yard

NEW YORK HARBOR
Brooklyn 27th Street Yard
Brooklyn 56th Street Yard
Hoboken Yard
Staten Island Yard

BALTIMORE HARBOR
Baltimore Yard

GULF COAST
Beaumont Yard
(Beaumont, Texas)

SAN FRANCISCO HARBOR
San Francisco Yard

LOS ANGELES HARBOR
San Pedro Yard

General Offices: 25 Broadway, New York 4, N.Y.

KINGSBURY THRUST and JOURNAL BEARINGS
THE NAVY'S CHOICE FOR 40 YEARS
Kingsbury Machine Works, Inc. KINGSBURY Frankford, Philadelphia 24, Pa.

GIBBS & COX, INC.

NAVAL ARCHITECTS

AND

MARINE ENGINEERS

NEW YORK

The second and third POLARIS equipped submarines were launched this past Summer. USS PATRICK HENRY (SSBN-599) was launched on the East Coast while USS THEODORE ROOSEVELT (SSBN-600) took to the water on the West Coast. Each will be equipped with the Ship Inertial Navigation System (SINS) which will enable it to accurately determine its position while remaining submerged for long periods of time. In addition to its missile armament each ship will carry a torpedo battery. PATRICK HENRY is being completed at the Eletcric Boat Division of General Dynamics Corporation at Groton, Conn., and THEODORE ROOSEVELT is being completed at Mare Island Naval Shipyard.

—Defense Department News Release

New Dutch Flagship completes maiden voyage

350 years after arrival of "Half Moon"

On September 11th, New York Harbor welcomed the Rotterdam, Holland-America Line's newest, largest and most modern liner.

The arrival of this 38,645-gross tonnage ship recalls the historic day 350 years ago when the Dutch vessel Half Moon first dropped anchor off Staten Island.

Ranking fifth in size among the world's passenger ships, the Rotterdam is fitted with all the improvements that modern engineering can provide for safety and comfort at sea.

Combustion Engineering had a very special interest in extending a hearty welcome to this notable ship, for the power that drives her is supplied by 4 boilers of C-E VERTICAL SUPERHEATER design, built by N. V. Koninkijke Maatschappij "De Schelde," Combustion's licensee in Holland. Each boiler has a normal rated capacity of 110,000 pounds of steam per hour. The Rotterdam is another notable ship added to the rapidly growing list of those powered by C-E Vertical Superheater Boilers.

Around the world Combustion Engineering continues to provide the most advanced designs of steam generating equipment for merchant and naval ships—including our Nuclear Navy.

COMBUSTION ENGINEERING C-E

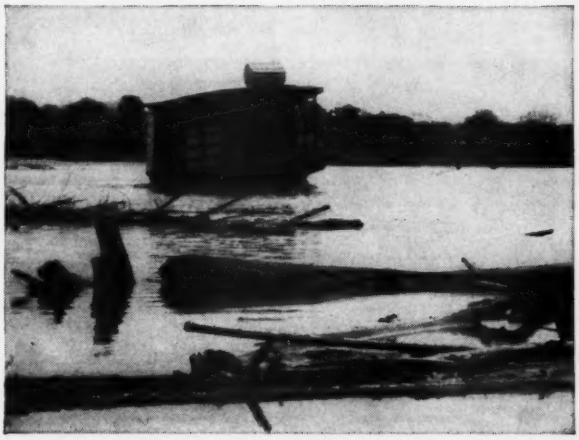
Combustion Engineering Building • 200 Madison Avenue, New York 16, N. Y.

C-242A

Canada: Combustion Engineering-Superheater Ltd.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Jungle missionary straightens out shaft problem



Hazardous passage. Drifting debris, submerged rocks and ever-shifting shoals pose constant threats to this missionary. He is Brother Dismas of the Maryknoll Fathers, whose frequent missions take him up and down uncharted, unpredictable waters deep in the jungles of Bolivia.

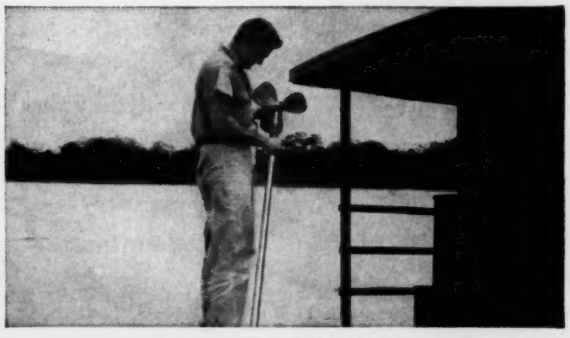
There's no telling what he may run into here. One of the menaces is the dead *Tajibu* or "vegetable iron" tree.

A giant hardwood, the *Tajibu* dies and topples into the river. The wood is so heavy the whole tree sinks. And so *hard* it's been used in place of bearing metal. Imagine what happens when a *Tajibu,* cartwheeling along in the swiftly running current, tangles with the boat's slender drive shaft . . ! It's virtually impossible to detect one fast enough to avoid being rammed.

Man-eating Piranhas and alligators lurk in these jungle rivers, but Brother Dismas dives in and removes bronze propeller shaft, bent in collision with an unseen *Tajibu.* With nearest help several days' journey away, he has no alternative but to attempt an on-the-spot repair.

Riverside "shop"—The bent bronze shaft is first heated over an open fire, then placed on a log and hammered straight. This primitive repair job has to get him back to his base. "After a few experiences like this, I got a bright idea," says Brother Dismas. "I decided to try one of your Monel shafts."

"Monel shaft arrives"... and was I glad to see it. I've found that bronze shafts bend too easily in these rivers and steel shafts corrode and chew up bearings. We picked up our new Monel shaft in an ox cart at the airport and were underway with it in record time. Now we have...

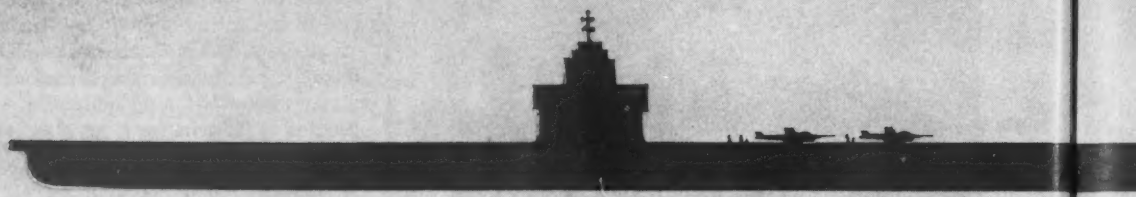


"A sturdy shaft at last!" For a better idea on how to get longer service from shafts, fuel and water tanks, fastenings and rigging — and a simple explanation of how corrosion can destroy marine equipment, write for our illustrated booklet, "When Metals Go To Sea." Gives details on shafts and other fittings. *Inco trademark

HUNTINGTON ALLOY PRODUCTS DIVISION • **The International Nickel Company, Inc., 67 Wall St., New York 5, N. Y.**

MONEL®

Code: CGN . . . Guided-missile Cruiser
CVAN . . . Attack Carrier
DLGN . . . Guided-missile Destroyer
SSN . . . Fleet-type Submarine
SSRN . . . Radar-picket Submarine
SSGN . . . Guided-missile Submarine
SSKN . . . Hunter-killer Submarine
SSBN . . . Ballistic-missile Submarine



CVAN ENTERPRISE

CGN LONG BEACH

DLGN BAINBRIDGE

SSN NAUTILUS

SSN SKATE

SSN SWORDFISH

SSN SARGO

SSN SEADRA

SSN SCAMP

SSN SCORPION

SSN SCULPIN

SSN SHARK

SSN THRESHER

SSN PERMIT

SSKN TULLIBEE

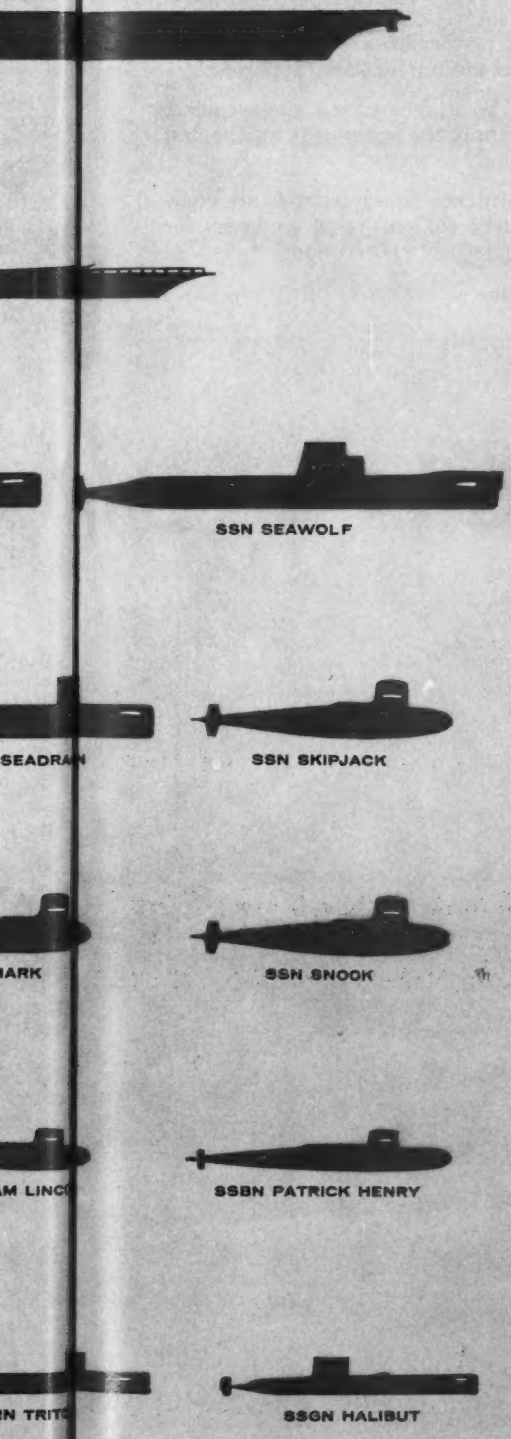
SSBN ABRAHAM LINC

SSBN THEODORE ROOSEVELT

SSBN ROBERT E. LEE

SSBN GEORGE WASHINGTON

SSRN TRIT



5 years ago

WORTHINGTON ENLISTED IN THE NUCLEAR NAVY

All of the Navy's 25 nuclear vessels in operation or under construction will carry Worthington equipment.

When the Nautilus went to sea in January, 1955, there were several Worthington pumps on board. These included main and auxiliary circulating pumps, main and auxiliary condensate pumps, plus reactor fresh water pumps and other miscellaneous service pumps. From this beginning Worthington has continued to supply the U. S. Navy with vital equipment for nuclear ships. Twenty-five of the twenty-five nuclear ships in operation or under construction, plus 11 authorized by Congress will carry Worthington equipment.

High Pressure Air Compressor for Polaris Ballistic Missile Submarines

The new SSB (N)-598 Class nuclear submarines, of which the recently launched "George Washington" is the first, will go to sea with three Worthington high-pressure, 4500 p.s.i. air compressors on board. A noteworthy "first," these units will furnish pressurized gas to expel the I.R.B.M.'s from their tubes and will also be used for torpedo ejection. At lower pressures, they will be used for water ballast control, low pressure operation of escape hatches and for energizing hydraulic accumulation to operate the periscope, antennae and other mechanisms.

Primary Coolant Pumps (Canned)

Worthington is proud of its part in the development of canned rotor pumps for circulating primary coolant in reactor systems. These motor driven units feature a number of significant design advances.

Reactor Buffer Seal Charging Pumps for N. S. Savannah

Worthington will also go to sea on the first nuclear merchant vessel, the N.S. Savannah. Worthington reactor buffer seal charging pumps are another noteworthy "first" in application and design. As dual purpose units they not only charge the reactor but also provide the vital service of sealing all the reactor control rods.

In addition, many other units of secondary cycle and ship's equipment are being built by Worthington.

For more information about Worthington marine products, get in touch with your nearest Worthington district office. Or write to Worthington Corporation, Section 106-4, Harrison, N. J.

WORTHINGTON

MARINE EQUIPMENT BUILT BY WORTHINGTON FOR NUCLEAR VESSELS

- High pressure air compressors
- Low pressure air compressors
- Heat exchangers
- Deaerating feed tanks
- Hydraulic ends for reactor circulating pumps (canned)
- Reactor system charging pumps
- Reactor fresh water pumps
- Decay heat removal pumps
- Circulating pumps
- Condensate pumps
- Drain pumps
- Bilge pumps
- Snorkel de-icing pumps
- Gyro-stabilizer pumps
- Trim & drain pumps
- Distilled plant pumps

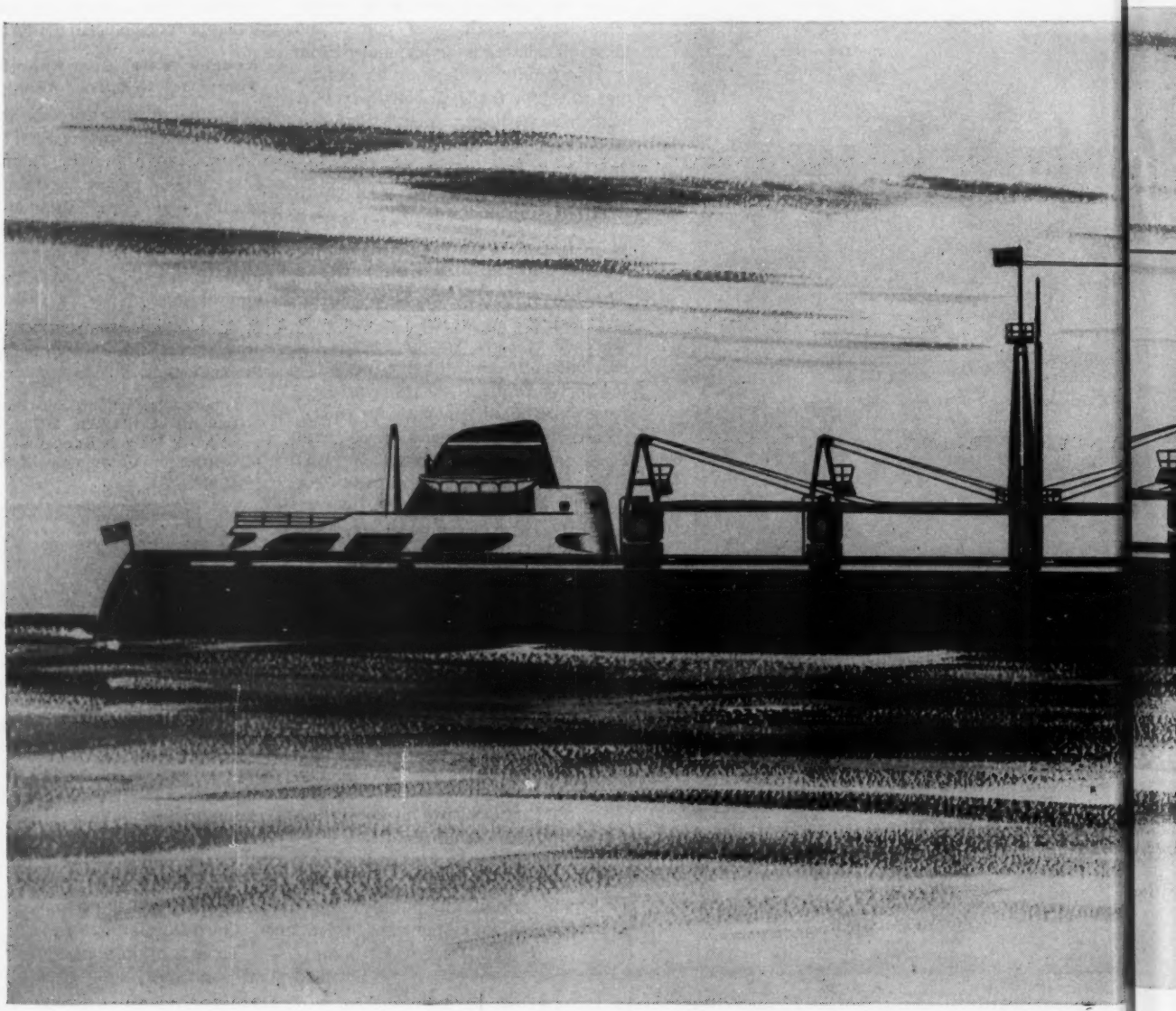
NEW MERCHANT FLEET POWERED BY WESTINGHOUSE

Avondale Marine Ways, Inc., uses single-source supplier for all steam and electrical equipment!

To build a new design cargo ship for the Mississippi Shipping Company, operators of Delta Line, many advantages of one source, one responsibility for design, delivery and performance of all steam and electrical equipment are immediately apparent.

Avondale chose Westinghouse—a single-source, single contact, to supply the equipment for the first three ships to be built.

- Equipment performance characteristics are coordinated by teams of skilled design engineers for highest over-all efficiency and economy.



- A single source assures coordinated effort for planning, manufacture and delivery of products from 20 or more plants.
- A single contact saves time and money in obtaining design, engineering, and delivery information.

You, too, can obtain the advantages of a single-source supplier when specifying equipment for your next vessel. Westinghouse's record as a leading supplier of long-lasting, low-maintenance equipment for merchant and naval ships is your assurance of outstanding quality and performance.

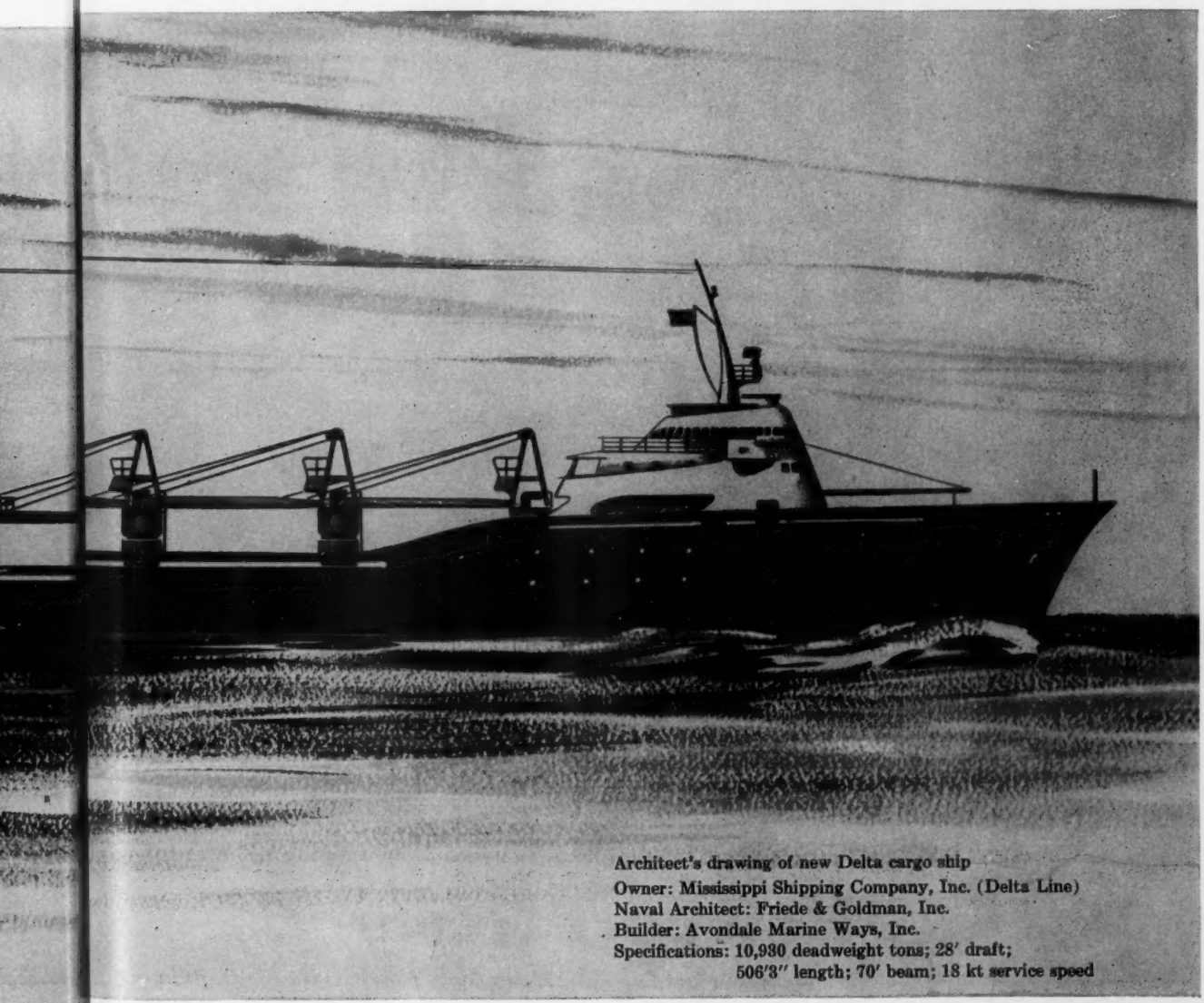
For information on your specific requirements, contact your local Westinghouse office or write: Westinghouse Electric Corporation, P.O. Box 868, 3 Gateway Center, Pittsburgh 30, Penna.

The Delta liner-of-the-future is a modern, engine aft, cargo vessel designed for operation with maximum efficiency between U. S. Gulf ports and shallow draft ports of West Africa and South America. For high-speed cargo handling, the ship has a new cargo hold design and cranes which operate along the full length of the deck.

Westinghouse equipment specified for these vessels: Main propulsion turbines and gears • Ship service turbine-generator • Main and auxiliary condensers and air ejectors • Forced draft blowers • Hull ventilation equipment • Switchgear • Panelboards • Transformers • Under-deck motors and controls • D-C cargo crane and winch drives J-92038

YOU CAN BE SURE...IF IT'S Westinghouse

Watch "Westinghouse Lucille Ball-Desi Arnaz Shows" CBS-TV Fridays



Architect's drawing of new Delta cargo ship
Owner: Mississippi Shipping Company, Inc. (Delta Line)
Naval Architect: Friede & Goldman, Inc.
Builder: Avondale Marine Ways, Inc.
Specifications: 10,930 deadweight tons; 28′ draft; 506′3″ length; 70′ beam; 18 kt service speed

Mechanical drawing class of Apprentice School students at Newport News. Those who excel advance to the technical drafting departments.

Shop training scene which shows an apprentice shaping a small die on a shaper, indicates how students are thoroughly trained.

How Skills are born... at Newport News

Newport News utilizes the skills of almost every known trade...

And for the past three and a half decades, this Company's Apprentice School has furnished substantial numbers of the trained leaders and skilled craftsmen who make outstanding ships the tradition of Newport News.

This school's faculty . . . including experts for both shop practice and academic subjects . . . provides instruction equivalent to a Junior College education during four and five year courses.

Graduates numbering some 2200 skilled workers in 20 separate crafts comprise one more reason why quality identifies everything produced at Newport News.

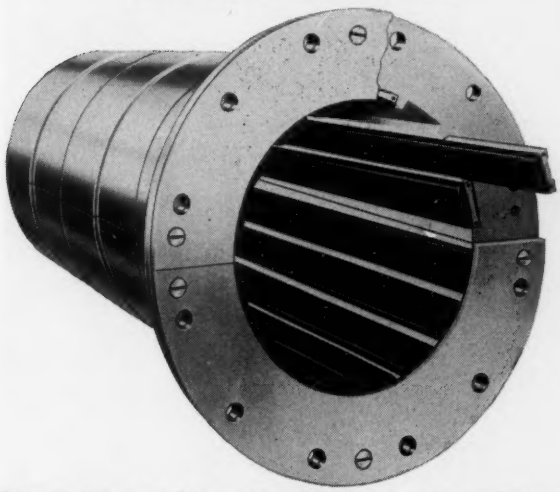
Newport News

Shipbuilding and Dry Dock Company • ***Newport News, Virginia***

CUTLESS BEARINGS

for

Stern Tubes and Struts



Soft rubber bearing surface—efficiently lubricated by water—this bearing far outlasts all hard surface types, protects propeller shafts, reduces vibration. More than pays for itself in extra wear alone. Saves you time, trouble, and upkeep expense.

LUCIAN Q. MOFFITT, INC.

Akron, Ohio

JOHNS-MANVILLE JM PRODUCTS

Materials for MARINE SERVICE

Incombustible Joiner Materials • Acoustical Materials

Asbestos Ebony for Switch and Panel Boards • Structural Insulations

Boiler and Engine Room Insulations • Packings • Gaskets

Johns-Manville

Box 290, New York 16, N. Y.

H. NEWTON WHITTELSEY Inc.

NAVAL ARCHITECTS **MARINE ENGINEERS**

17 BATTERY PLACE, NEW YORK 4, N. Y.

WHitehall 3-6280 **Cable: WHITSHIP**

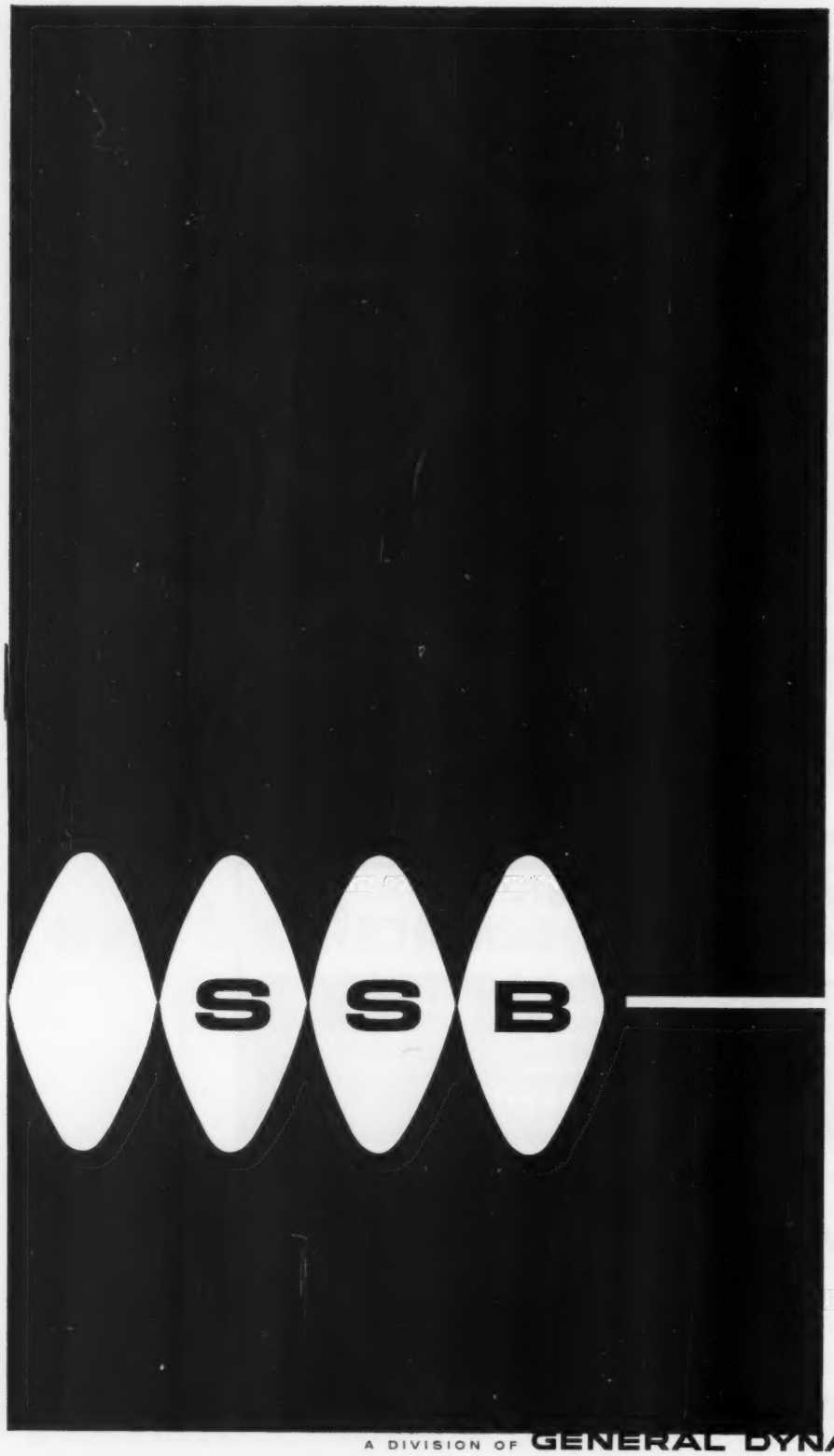
NAVAL ARCHITECTS

MARINE ENGINEERS

M. ROSENBLATT & SON, Inc.

NEW YORK CITY
350 BROADWAY
BEekman 3-7430

SAN FRANCISCO
216 MARKET ST.
EXbrook 7-3596



Stromberg-Carlson is now developing for the Armed Forces... Advanced Single Sideband radio applicable to shipboard, vehicular and airborne communications.

The simplifying of both transmitting and receiving circuits in this digital-tuned radio marks a significant advance in Single Sideband reliability, economy and ease of operation.

Broad-banded circuits and a unique frequency synthesizer eliminate servo amplifiers and motors, discriminators and rate generators.

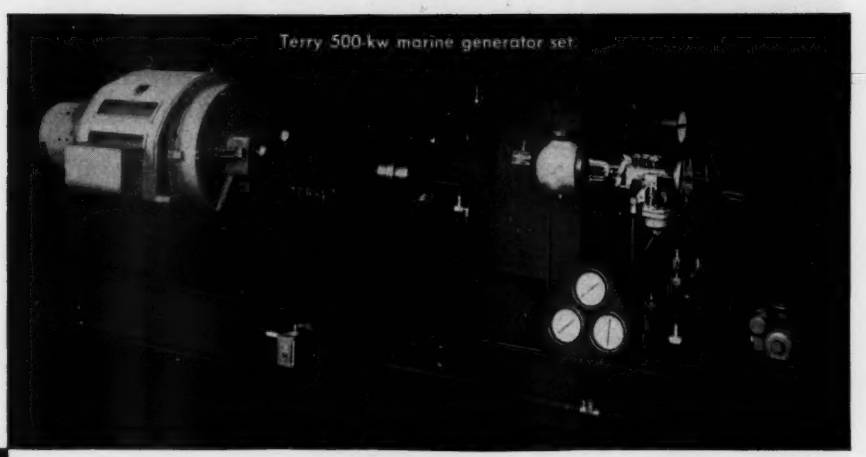
Heat-sink cooling eliminates blowers and air filters.

Brochure on request.

A DIVISION OF GENERAL DYNAMICS

1400 N. GOODMAN STREET • ROCHESTER 3, N. Y.

Terry steam turbines


Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
TERRY SQUARE, HARTFORD 1, CONN.

TT-1211

A combination of the Aerobee research rocket and the Sparrow military rocket are planned to be used to propel a plastic balloon to an altitude of about 300 miles to measure upper atmospheric density by drag data. At about 60 miles up, an eighteen pound package containing a 9-ft. Mylar plastic sphere will be ejected. It will be inflated at low pressure by the evaporation of ethyl alcohol. A hollow plastic diametral strut will be inflated to a higher pressure by a small capsule of freon. At the midpoint of this strut, the instrument can will be located. Containing a radio transmitter and necessary instruments, the can will collect and transmit drag data as the balloon follows the trajectory of the projectile up to a zenith of about 300 miles. The heart of the instrumentation is a special accelerometer, designed to measure as low as one hundred-thousandth of a g.

—from JOURNAL OF THE FRANKLIN INSTITUTE
August 1959

BETTER CONTROL OF ANCHORS AND CHAINS

from the extra experience at AE

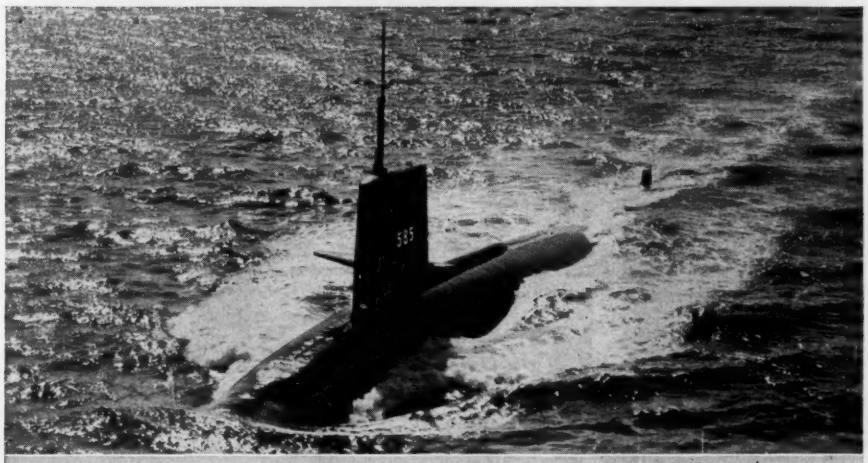
Today's advances in ship design... the increases in size and tonnage... the continuing changes in ship handling... the more general use of offshore mooring . . . impose new and more critical responsibilities on anchor windlasses. AE-engineered windlass assemblies, with their proven braking systems, are extra responsive, extra-efficient . . . extra sure!

Among marine men *who know*, AE-engineered windlasses have gained a reputation and stature for simplification of design, reduced maintenance, and . . . *more reliability*, the basic factor that is always automatically engineered into all AE products as a result of our extra years of *experience*. Tell us your windlass needs . . . get the touch of extra experience. Write or call AMERICAN ENGINEERING COMPANY, Phila. 37, Pa., Dept. M-122, Phone CUmberland 9-3800.

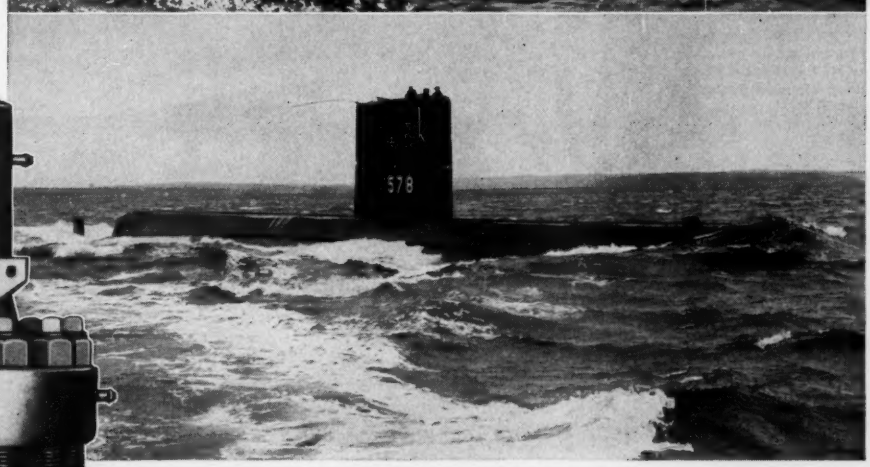
AMERICAN ENGINEERING COMPANY

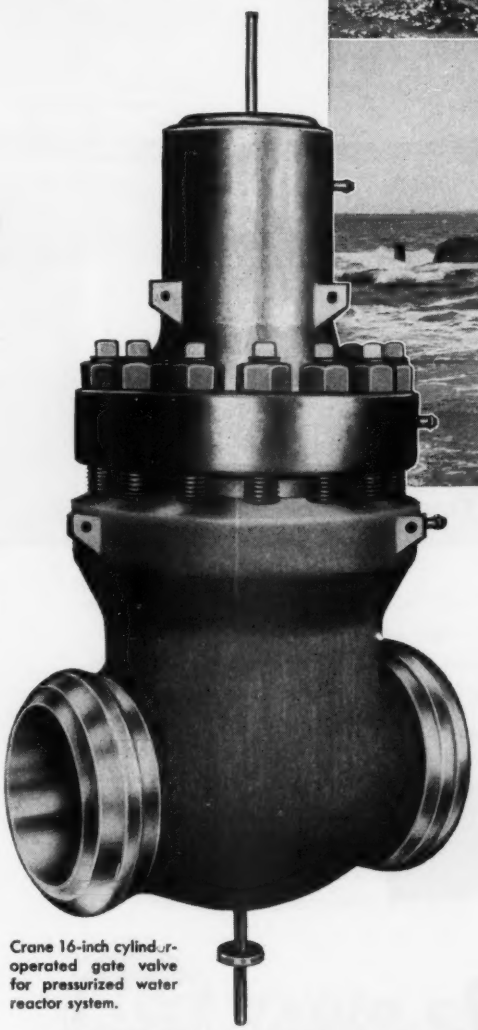
Steering Gears • Windlasses • Winches • Capstans • Hele-Shaw and Hydramite Fluid-Power

Ever since nuclear power went to sea Crane valves have provided safe controls



U.S.S. Skipjack
(Below)
U.S.S. Skate
(General Dynamics Corp. photos)





Crane 16-inch cylinder-operated gate valve for pressurized water reactor system.

The daring imagination of naval pioneers who first powered submarines with atomic reactors was matched from the beginning by the resourcefulness, knowledge and skill of Crane engineers and craftsmen.

From their drawing boards, foundries and machines came valves that provided safe flow control of the radioactive materials making nuclear-powered propulsion possible.

Today Crane valves go to sea on reactors and auxiliary service lines on board the *Nautilus* . . . *Seawolf* . . . *Skate* . . . *Sargo* . . . *Skipjack* . . . *Swordfish* . . . *Seadragon* . . . and they will be on many other submarines still to be built.

Crane valves will be aboard nuclear-powered surface ships, too: the cruiser *Longbeach* . . . new destroyers and carriers. And they're on the new passenger-cargo ship *N/S Savannah*.

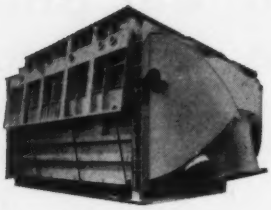
If your plans for ships or naval power plants call for atomic energy as fuel, consult your Crane Representative now for information about these valves—or write to address below.

CRANE® VALVES & FITTINGS

PIPE • PLUMBING • HEATING • AIR CONDITIONING

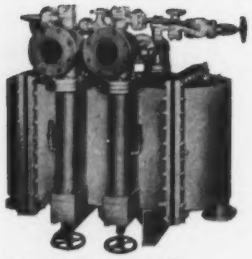
Since 1855—Crane Co., General Offices: Chicago 5, Illinois—Branches and Wholesalers Serving All Areas

For

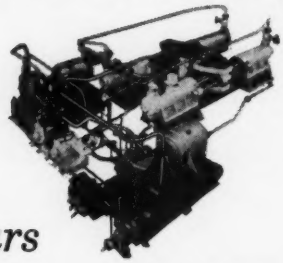


Marine Condensers,

C.H. Wheeler Condensers, main and auxiliary, occupy little room, weigh comparatively little, have Center Lane Tube Layout to speed longitudinal steam travel and permit quick penetration of steam to bottom row of tubes.



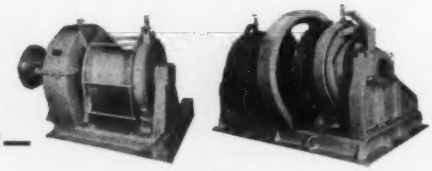
Tubejet® Ejectors, Steering Gears



C.H. Wheeler Tubejet® Ejectors answer problems raised by today's high boiler pressures and temperatures. They remove large quantities of vapors at high vacuums. Light, compact, dependable, too!

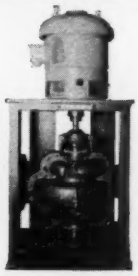
Electro-Hydraulic Steering gears are available in a complete range of sizes for every type vessel, from tug boats to supercarriers. C.H. Wheeler also makes automatic, self-centering, springless telemotors and rotary telemotors.

and Telemotors—



Deck Machinery and

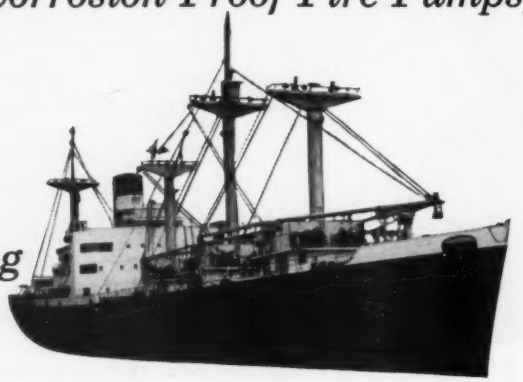
C.H. Wheeler Deck Machinery includes Electric and Hydraulic Winches, Electric Hydraulic Windlasses, Electric Warping Capstans, Boat and Aircraft Cranes, Automatic Tensioning Hoists and Elevators.



High-Capacity Corrosion-Proof Fire Pumps; for

Corrosion-Proof Fire Pumps designed and manufactured by C.H. Wheeler provide maximum gpm at medium and high heads; offer dependable, low-maintenance performance and take little space in the hold.

nearly everything



but the hull, see:

Marine Division

C. H. WHEELER MFG. CO.

19TH & LEHIGH AVENUE
Philadelphia 32, Pennsylvania

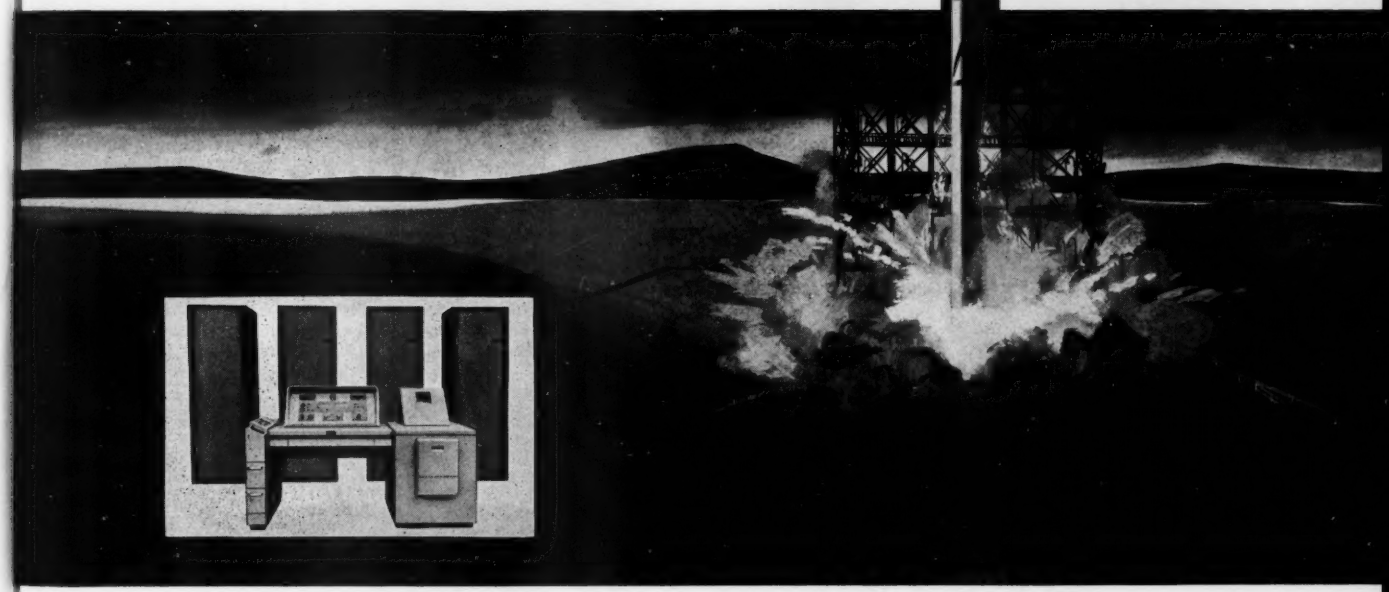
Whenever you see the name C. H. Wheeler on a product, you know it's a quality product

Marine Condensers, Ejectors, Pumps and Auxiliary Machinery • Steam Condensers • Steam Jet Vacuum Equipment • Centrifugal, Axial and Mixed Flow Pumps • Nuclear System Components

The Checkout that says "GO" or "NO GO"

APCHE

(Pronounced "AP-SHE")



APCHE (Automatic Programmed Checkout Equipment) is a solid-state, universal, high-speed, highly reliable, compact general-purpose tester designed especially for automatic checkout of aircraft, missile and space systems and their supporting systems. In its various versions (differing in input media, size and weight) APCHE installations may be fixed, mobile, airborne or submarineborne. APCHE was designed and is being produced as a part of RCA's ground support electronics subcontract from the Convair (Astronautics) Division of General Dynamics Corporation, prime contractor for the ATLAS Intercontinental Ballistic Missile.

The system being supplied to Convair for the ATLAS Program includes a console and four rack cabinets providing both analog and discrete test functions with a resulting printed and GO-NO GO indication. As a product of RCA's Missile Electronics and Controls Department, Burlington, Massachusetts, APCHE is one of the latest RCA developments in the field of military weapon readiness equipments.

RCA Tmk(s) ®

RADIO CORPORATION of AMERICA

DEFENSE ELECTRONIC PRODUCTS • CAMDEN, NEW JERSEY

Main condenser on new supertanker tubed with Anaconda Cupro Nickel, 10%-755 for long service life

In naval service, cupro nickel tubes have established enviable records of long service life. And now owners of large commercial vessels are taking advantage of cupro nickel's high corrosion resistance to counteract the very high costs of taking such vessels out of service for too-frequent retubing of condensers.

The new supertanker, S.S. Sansinena, uses 6,940 tubes of Anaconda Cupro Nickel, 10%-755 in its main condenser. Each is ¾" O.D. x .065" gage x 16' 2¾" long, and total cooling surface is 21,800 sq. ft. The American Brass Company also furnished the 2 leaded Muntz Metal plates for the tube sheets of the main condenser, each 127½" x 131½" x 1¼"—and 2 circular plates of leaded Muntz Metal for the tube sheets of the auxiliary condenser, each 78" diameter x 1⅛" thick.

Cupro Nickel, 10%-755 was developed by The American Brass Company to provide much of the high corrosion resistance of Cupro Nickel, 30%-702 at considerably lower cost. It is highly resistant to corrosion by turbulently flowing sea water and is being used increasingly not only on shipboard but also on land—wherever corrosion conditions are severe and continuity of service is important.

It is used in *stationary steam power plants* to handle either clean or polluted sea water, even at relatively high velocity of flow. And in the *petroleum industry* tubes of Cupro Nickel, 10%-755 are used in heat exchangers handling sulfur-free streams in a number of tidewater oil refineries.

TECHNICAL ASSISTANCE in the selection of alloys to meet special problems is yours for the asking. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ontario. 5909B

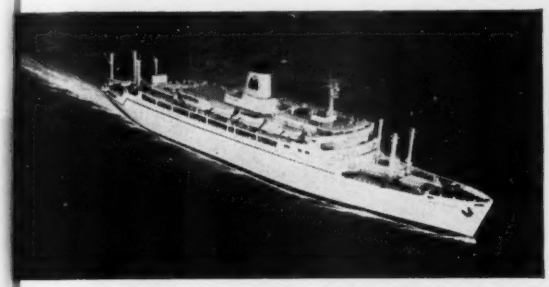
ANACONDA®

TUBES AND PLATES FOR CONDENSERS AND HEAT EXCHANGERS
Made by
THE AMERICAN BRASS COMPANY

Pioneer work by the Lamp Division of the Westinghouse Electric Corporation in the field of electro-luminescent phosphors has been based on the excitation of phosphor powders by alternating current to produce visible light. This has enabled the construction of lamps in flat sheets, a recent development which will strongly influence illumination design in the future. However, the response of phosphors to an AC field is only one aspect of their unusual behavior. It has been found that they are also sensitive to DC fields and to radiation in the near-ultraviolet regions of the spectrum. The most striking aspect of the response of the phosphors is their behavior to a combination of excitation sources. Under certain conditions, it is noted that the total light emission resulting from two simultaneous excitation sources considerably exceeds the sum of the light emissions resulting from the sources acting singly. The multiplication factor may be a hundred or more. Combinations of AC and DC excitation, AC plus ultraviolet radiation and DC plus ultraviolet radiation have been studied. Some of the possibilities for engineering applications of these phenomena are light and image amplifiers; decoupling audio o- DC amplifiers; switch and relay units; and on-off indicators.

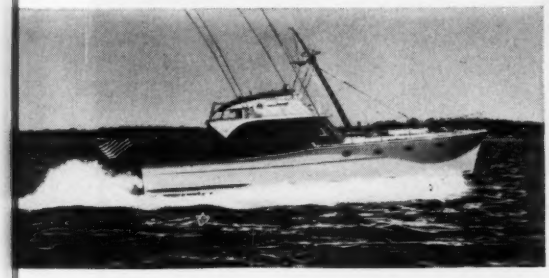
—from WESTINGHOUSE ENGINEER
August, 1959

S. S. UNITED STATES maintains record for fast, on-schedule Atlantic crossing, with Sperry Gyro-Compass establishing course, Sperry Gyropilot holding that course precisely and Sperry Radar providing clear "view" through darkness and fog.



S. S. MARIPOSA, luxury cruise ship of Matson Line, was first liner to install Sperry Gyrofins for stabilization. Gyrofins reduce ship's roll up to 90%. Wheel-type gyroscopic stabilizers will control the roll of missile-launching Polaris submarines.

WEEKEND SAILORS and smaller commercial vessels now get advantages of specially-designed Radar, Loran, Automatic Steering and other aids formerly limited to larger vessels.



IN SIMULATED SUBMARINE, engineers test revolutionary Sperry system which permits celestial navigation while submerged to periscope depth. Utilizing sun, moon or stars, SCAR (Submarine Celestial Altitude Recorder) automatically computes position and supplies data in printed form. Other Sperry instruments and controls enable subs to maneuver like airplanes—climbing, banking and diving automatically with precise control.

Making A Free World Seaworthy

Subs that "shoot" stars when submerged and "fly" through the deep join achievements of engineers who made ocean travel safer, more dependable

ONE OF A SERIES:

THE STORY BEHIND THE STORY
of Sperry Piedmont Company

Until Sperry developed the Gyro-Compass, no ship at sea ever knew her exact heading. At best, compasses of the day gave only approximate bearings and the slightest electrical storm or magnetic disturbance upset them completely and required hours or days for proper corrections. By making it possible to determine True North, Sperry gave the world its first precision navigation. That was in 1911—and the first Sperry Gyro-Compass has been succeeded by scores of Sperry developments in navigation that make ocean travel safer, more comfortable . . . commercial shipping more profitable . . . family boating more pleasant . . . and the defenses of the free world more effective.

The Sperry Gyropilot® holds ships on course far more accurately than any human helmsman. Sperry Gyrofin® Ship Stabilizers, now in use on many vessels, protect passengers and cargo and help to avoid slow-downs due to rough seas that ruin schedules. Sperry Radar, with its needle-sharp resolution, "sees" through fog and storm to pick up other ships, landfalls, buoys and similar obstacles—while Sperry Loran gives the ship's captain his absolute position at all times, even when celestial "fix" is impossible.

Today Sperry equipment is available for more ships than ever before. Through the facilities of its modern new plant, new navigation aids have been added that meet the needs—in size and price—of nearly every pleasure or commercial craft. For information write Sperry Piedmont Company, Division of Sperry Rand Corp., Charlottesville, Virginia.

SPERRY

LESLIE FOR CONTROLS

Out here, if a control valve or regulator fails there's no place to go for repair facilities or replacement parts. Delay can mean late arrival, cargo spoilage and loss of profit. Shipowners, operators and builders are aware of this hazard. That's why 95% of America's merchant and naval vessels are Leslie-equipped.

This overwhelming preference for Leslie is based on sound reasons. Leslie reliability means trouble-free service, maximum resistance to corrosion and wear, and lower overall operating cost. Leslie quality is based on nearly 60 years of experience in designing and producing equipment for the marine industry.

Leslie products include *reducing valves* for steam, air and water services; *temperature regulators* for steam and water systems; *pump pressure regulators* for steam driven pumps and turbines; *pilot mechanisms and diaphragm control valves* for liquid level and pressure and temperature control; and Leslie-Tyfon steam and *air whistles*. Write for complete engineering and application data.

TRADE LESLIE MARK **REGULATORS and CONTROLLERS**

Leslie Co., 413-C Grant Ave., Lyndhurst, New Jersey

ENGINEERED FOR MARINE SERVICE

Diaphragm control valves

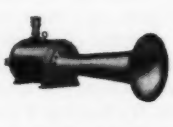
Control pilots for pressure, temperature and level

Pressure reducing valves

Temperature regulators

Pump pressure regulators, Differential pressure regulators

Strainers



Steam and air whistles, automatic whistle controls

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and County is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CAPTAIN ROBERT B. MADDEN, U. S. NAVY.

Commander Charleston Naval Shipyard,
Assistant Secretary-Treasurer ASNE 1 January 1951 to 16 November 1959

Copyright 1959, by the American Society of Naval Engineers, Inc.

Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 71 NOVEMBER, 1959 NUMBER 4

Statements contained in articles herein are the private opinions and assertions of the writers and should therefore not be construed as reflecting the views of the AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., nor of any other organization with which such writers are affiliated. The Society as a body is not responsible for statements made by individual members.

COUNCIL OF THE SOCIETY

(Under whose supervision this number is published

Rear Admiral WILLIAM A. DOLAN, JR., USN, President

Captain JAMIE ADAIR, USN
Commander R. S. BURPO, JR., USNR
Mr. HUGH E. CARLETON
Commander JOHN A. COIL, USN
Mr. GILBERT S. FRANKEL
Captain IVAN MONK, USN
Lt. Comdr. DONALD E. REDMON, USNR
Captain THOMAS W. ROGERS, USN
Rear Admiral E. H. THIELE, USCG

Captain J. E. HAMILTON, USN (Ret.), Secretary-Treasurer

NAVAL ENGINEERING

Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

Meetings

Council meetings were held on 29 August and 13 October 1959 and the Annual Meeting of the Society took place on 13 October 1959. Current business was discussed at these meetings and some decisions were reached. These are discussed below under their own subject headings.

Assistant Secretary-Treasurer

Perhaps the most important and, to the Secretary, the most distressing thing which occurred at these meetings was the announcement that Captain Robert B. Madden, U.S. Navy was to become Commander of the Charleston Naval Shipyard at Charleston, South Carolina. Captain Madden left Washington on 16 November and is now in Charleston where he will assume command of the Shipyard on 2 December 1959. On his departure from Washington, Captain Madden was succeeded as Assistant Secretary-Treasurer by Commander Charles N. Payne, USN. Commander Payne is in the Preliminary Design Branch of the Bureau of Ships.

During the nearly nine years (since 1 January 1951) that Captain Madden has served the Society as Assistant Secretary-Treasurer, we have been thankful for our good fortune because Navy orders

did not remove him from the area to interfere with his outstanding contributions to the Society. Such luck could not continue forever and we must bow to the inevitable, accept our loss graciously and congratulate the personnel of the Charleston Naval Shipyard and the citizens of Charleston for their great acquisition.

Commander Payne is well acquainted with the operations of the Society since he has assisted us in getting material for the JOURNAL and has served on the banquet committee for several years. He is well qualified and will do a fine job in filling the shoes which Bob Madden has kept so well filled for so long.

CDR. CHARLES N. PAYNE, USN

We feel inclined to attempt to write a tribute to Captain Madden but phrases such as we could compose could not do proper justice to this man. Never have we enjoyed an association so much. Never have we gained more respect for a man than our good fortune in working with him for nine years has engendered. We had no difficulty in piercing his mask of humility and self effacement to find his true worthiness. We love, respect and admire him but will leave to a more worthy biographer the pleasure of describing his talents.

Due to the absence of the Editor, Captain Madden did the major part of the work on this issue of the Journal. It therefore seems doubly appropriate to dedicate this issue to him.

1959 Elections

A nominating committee composed of Rear Admiral E. A. Wright, USN; Captain C. H. Campbell, USNR; and Mr. C. Swan Weber proposed a slate of candidates for the next election. This was modified by the Council because of the pending ineligibility of Captain Madden and presented to the Annual Meeting where one name was added. The resultant ballot which was mailed to all voting members last month contained the names of candidates as follows:

For President 1960
Rear Admiral Robert E. Cronin, USN

For Secretary-Treasurer in 1960 (One to be elected)
Captain J. E. Hamilton, USN (Ret)
Commander Charles N. Payne, USN (Substituted for Capt. Madden by Council action)

For Regular Navy Council Members in 1960 (Two to be elected)
Rear Admiral M. J. Lawrence, USN
Captain James E. Halligan, USN
Captain John J. Fee, USN
Captain Frank C. Jones, USN

For Coast Guard Council Member in 1960 (One to be elected)
Rear Admiral E. H. Thiele, USCG
Captain Gilbert F. Schumacher, USCG

For Reserve Officer Council Member in 1960 (One to be elected)
Lieutenant (jg) Robert L. Kelly, USNR
Commander Ralph S. Lorimer, USNR
Commander Charles W. Overton, USNR
(Added from the floor at the Annual meeting)

For Civilian Council Member in 1960-1 (One to be elected)
Mr. Don Caffery Glassie
Mr. Harold H. Hill

Officers elected will take office on 1 January 1960. The results of the election will be published in the February 1960 issue of the JOURNAL.

Note: We deeply regret that the first ballot which we mailed, through error, carried Cdr. Overton's name under the "Civilian" category. A correct ballot was mailed as fast as possible after the error was discovered by Miss Leonard. Since the first ballot will not be counted, we hope that each member will be sure that he has filled out and mailed the second one.

Changes in By-Laws

In addition to the slate of candidates for office, the 1959 ballot carries two proposed changes in the By-Laws. The first of these which provides that the Secretary-Treasurer be Council-Appointed rather than Member-Elected was discussed in the Secretary's Notes in both the May and August 1959 issues of the JOURNAL.

The second proposal is simply a matter of keeping

abreast of the Navy Department organization. It will provide that the Chief of the Bureau of Naval Weapons rather than the Chiefs of the Bureau of Aeronautics and Ordnance will be an Honorary Member of the Society.

1960 Banquet

The A.S.N.E. Banquet which has become an annual affair will be held in 1960 on Friday, 29 April 1960. The location again will be the Statler-Hilton Hotel in Washington, D. C. Rules for attendance and arrangements for the banquet will be essentially the same as in 1959. Since it was necessary to refuse some applications in 1959 because their number exceeded the capacity of the hotel, an attempt will be made to take care of a somewhat larger number in 1960.

Provision will be made on the application for entry of the year in which the member joined the Society. For individual applications or parties of two, an effort will be made to give special consideration in the assignment of seats to those members of long standing.

Applications for the 1960 banquet may be expected in the mail in late January or early February. No applications which are received other than on the printed 1960 form can be given any consideration. We have no machinery for handling letter requests for reservations in advance.

Nature of Membership in A.S.N.E.

Membership in the American Society of Naval Engineers is strictly a personal and individual matter. We DO NOT have Company Memberships. This is clearly indicated on the application form which each new member signs before being admitted.

In spite of this there continues to be misunderstanding which arises in a few cases every year. Certain members have joined the Society because of their company affiliations at the time and have had their dues paid by their companies. However, neither of these features had any bearing on the granting of membership and this should be recognized by the member. Later when the company stops paying the annual dues because of change of position, retirement, termination of employment or other reason, the member affected assumes that this automatically severs his connection with the Society. This can not be. The By-Laws provide that honorable termination of membership is possible only by formal personal resignation with dues paid to date or by death. Automatic termination will come by dropping from the rolls with an open indebtedness of unpaid dues at any time that a member fails to pay his dues by 31 December of the year to which they apply. No reinstatement is possible without full satisfaction of this indebtedness.

We hope that hereafter all members will appreciate this situation and that those who wish to terminate membership do so in the only fully acceptable manner.

Naval Engineers

In the Secretary's Notes of the August 1959 issue, under this head we published something of the philosophy of being a member of the Society. In commenting on this, Captain Henry C. Dinger, USN Retired who is, as he points out, the oldest living Secretary-Treasurer of the Society, has written the following letter. We publish it in full as a matter of historical interest:

"To the Secretary-Treasurer A.S.N.E.

The comment of the Secretary in the August number of the JOURNAL is of particular value as a way of defining the purpose and aim of the Society, its JOURNAL and Banquet. Since I believe that I am the oldest living Secretary, the originator of the Banquet, and a membership of fifty-seven years, may I be permitted some few remarks.

Although not recorded, there really was a purpose behind the giving of the Banquets. It was a propaganda measure for the Naval engineers and their JOURNAL. At this time, in 1909, the engineers were being kicked around by the Newberry system, and for several months had even lost their Bureau of Engineering. By giving the Banquet it was hoped that the prestige of the Navy and Naval engineers would be increased among the authorities, Congress, the shipbuilding industry and the public. Accordingly invitations were issued to leaders in Congress, press representatives, prominent engineers, etc. These guests were requested to respond to toasts dealing with their several activities. In this way it was expected the various speakers would explain themselves to the others, would get acquainted, secure cooperation and make the Navy better understood among legislators and industry. The guest list was deliberately made out with this end in view. This plan was used for quite a number of years and worked with great success.

The idea was to generate understanding and cooperation among the various agencies responsible for the production of Naval material. The guest list at these early Banquets was rather carefully planned and was not produced by accident.

I also note with interest the article on Bureau of Ships that E.D.O. has progressed materially since I drew up the memo for Admiral Griffin in 1915, which became the E.D.O. law.

Sincerely,

/s/Henry C. Dinger"

Machol Edge Index

We used the Machol Edge Index in the August 1959 JOURNAL and called for comments as to its utility. Since there is some additional cost in using

this index and since only three members expressed written approval of it, the Council decided after a lengthy discussion, unanimously, not to use the index hereafter. Since the external Table of Contents without the locator system seems to have merit, this issue carries a Table of Contents on the outside back cover. The cost of this is minor. Comments on this more simple addition to the JOURNAL will be appreciated.

Past Issues of the Journal

We have concluded arrangements with the

Johnson Reprint Corp.
111 5th Avenue
New York, N. Y.

to handle the distribution of copies of the JOURNAL dated prior to 1951. This embraces Volumes 1 (1889) through 62 (1950). Any orders, requests or inquiries which relate to these earlier volumes of the JOURNAL should be addressed to the above company. We will automatically forward any which are received by the Society.

For Volume 63 (1951) or later issues of the JOURNAL any inquiries should be addressed to the Society as heretofore.

A.S.N.E. Fiscal Policy

Because the Council felt that a formal fiscal policy for the operation of the Society was desirable, one has been formulated and was accepted by the Council at its August meeting. The statement of policy is printed below for the information of all members.

"This statement of fiscal policy of the American Society of Naval Engineers is promulgated by the Council as of 28 August 1959. It shall be effective and governing, subject to change by formal action of the Council at any time.

The Society shall constantly maintain a conservative fiscal policy.

The convertible net worth of the Society currently is about $50,000.00. It is the policy to increase this gradually until it has become about $100,000.00 and having attained this figure to maintain it at about this level. Hence, until such time as the convertible net worth as represented by investments to be described hereinafter, shall reach $100,000.00 the Council will give no consideration to extraordinary expenditures such as grants, scholarships or awards in addition to those in effect on this date, namely:

The ASNE Award
The Junior awards to graduates of the
U.S. Naval Academy
U.S. Coast Guard Academy
U.S. Merchant Marine Academy
The Brand Award

The check book balance shall be maintained by deposit of all receipts therein. The amount of the balance will be such as the Secretary-Treasurer deems to be necessary for current expenses. The check book balance is not to be considered as a part of the convertible net worth as this term is used above.

The convertible net assets of the Society in excess of the check book balance shall be invested in

A Bank Savings Account
Building and Loan or Savings and Loan Accounts
Federal Government securities or other bonds
Stocks in U. S. Corporations

which will be called the "investments" of the Society.

The Secretary-Treasurer will maintain an adequate working balance in the checking account. He will keep a bank savings account in which shall be deposited any momentarily excess working funds so that these funds may draw interest. He may transfer from savings account to checking account as necessary.

Whenever the savings account balance is such that it exceeds necessary money for expenses for the remainder of the calendar year by $5000.00, the Secretary-Treasurer shall inform the Council with his recommendations for investment.

Whenever the bonds fall due, the Secretary-Treasurer shall turn them in and shall deposit the proceeds in the savings account pending decision of the Council as to investment. Otherwise no Society investments shall be converted or changed except on specific instructions of the Council. Investments of the Society shall not be used for speculation.

Income from investments will be deposited in the checking account.

Investments of the Society will be carried on the books as assets in the capital account at the purchase price. Losses or gains on conversion will be accounted for as profit and loss.

The Secretary-Treasurer shall cause a copy of this statement of policy to be placed in the hands of each new member of the Council."

Dropping of Members

When the By-Laws were revised as of 1 January 1958, one change of importance was the stipulation that members who were in arrears of dues for one year would be dropped. Members were carried for two years before this action was taken. As a result of the change it was necessary that we drop 181 members as of 1 January 1959. That this action had to be taken was not generally understood as is evidenced by the fact that a considerable number of those dropped have requested reinstatement and have brought their accounts up to date.

A rather large number of members' dues for 1959 remain unpaid at this writing. We feel that some of this is brought about because of misunderstanding of the By-Laws provision. It is hoped

that by calling this to the attention of those members who do not want to be dropped for nonpayment of dues they will take steps before 31 December to bring their accounts into satisfactory shape.

State of the Society

It is usual at the Annual Meeting for the Secretary-Treasurer to make a brief statement as to the financial and membership state of the Society.

The originally approved budget for 1959, as published in the May issue of the JOURNAL, predicted a net gain of $2500.00 for the year. A revision of the Budget in August indicated a gain of about $1,000.00 more than the earlier prediction. It now appears that, due to a somewhat improved income situation, the actual gain for the year may be somewhat higher than expected. If this is realized and if a similar gain can be continued the fiscal policy which is presented earlier in these notes will be most timely.

THE ASNE AWARD

The ASNE AWARD was initiated in 1957 and inaugurated in 1958. The first award was made at the 1959 Banquet to Mr. Valor C. Smith of the Navy Electronics Laboratory for his outstanding contribution in the field of radio antenna design. All phases of this award have been discussed in the JOURNAL for well over a year. It is our purpose to make this award broadly known and recognized as one to be most coveted.

As the year 1959 approaches its end, it is time to be alert for the discovery of the most outstanding contribution in Naval Engineering which has been made by any American citizen during the year. When this is ascertained under the criteria established by the Society, the contributor will be honored for his 1959 action at the annual 1960 Banquet.

We are assured that there has been no slowing in the pace of technical advancement during 1959 and that much of this has taken place in Naval Engineering which we define as follows:

NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

The A.S.N.E. Award will be made to the American citizen who made the most outstanding contribution in the field of Naval Engineering during 1959 **and whose accomplishment is known to the Awards Committee and to the Council.** We have accented the critical element.

We are writing letters to a large number of officers and officials whose official positions put them where they can observe large segments of the field and we feel that few of them can have failed to note at least one performance which he considers to be outstanding. We are asking each of these to report this performance whether it be an idea, an invention, a concept, a writing or a physical deed.

By these letters we expect to cover a wide field and we hope that the response will reflect a full appreciation of what the Society intends its award to be.

But that kind of coverage cannot be complete. We are calling on 3400 members of the Society, to each of whom this notice is personally addressed, to report in the form of a citation any truly outstanding contribution which has come to his attention.

We know that many momentous things are being done. We hope that the most valuable of these will be cited to the Council so that the Awards Committee will be very hard pressed to make the one outstanding selection.

Please address your citations to

The Secretary-Treasurer (ASNE Award)
American Society of Naval Engineers
Suite 403, 1012 14th Street, N.W.
Washington 5, D.C.

so that it reaches us not later than 15 March 1960. The citation must be thorough enough so that the Committee can make a proper judgement on it.

The success of the ASNE Award will depend to a very great degree on the response by the Membership to this appeal.

The following press release of the INDUSTRIAL COLLEGE OF THE ARMED FORCES, Fort Lesley J. McNair, Washington 25, D.C., is of importance and, we believe, may be of real interest to many readers of the Journal:

"WASHINGTON, D.C.—You don't have to wear a uniform to 'attend' one of the nation's most senior joint military colleges.

The Industrial College of the Armed Forces, Fort Lesley J. McNair, Washington, D.C., offers a graduate level correspondence course to qualified civilians in business, industry, and the professions as well as selected officers of the reserves and of the regular components. This course is based on the curriculum of the 10-month resident course conducted by the college for selected senior officers of the military services and executives of the civilian agencies of the government.

The Industrial College which operates under the direction of the Joint Chiefs of Staff, is unique among military colleges of the world in that it studies the economic readiness of nations and blocks of nations to wage war, and analyzes the economic, military, political and psychological factors as they relate to the national security.

The correspondence course, 'The Economics of National Security,' portrays the interdependence of the economic and military structures. The text material is presented in 22 bound volumes of about 85 pages each, and is organized into five units of study. Members of the faculty review each test paper submitted and are available to answer individual questions. The entire course takes about one year to complete.

Since the course was first formulated in 1950, it has been repeatedly modified to reflect the changes in the world situation. Today over 3600 are enrolled in the course. Many major industries and companies recommend the course as part of their executive development program.

Civilians who successfully complete the course receive a certificate of completion. Reserve officers not on extended active duty are granted 48 credit points. There is no charge for the course.

Personnel interested in taking the course are urged to apply to the Commandant, Industrial College of the Armed Forces, Washington 25, D.C., Attn.: Correspondence Branch."

The Editor has taken this correspondence course and considers that the defense posture of the United States is enhanced by every person who completes the course.

CAPTAIN N. SONENSHEIN, U. S. NAVY

THE COSTS AND RISKS OF ENGINEERING PROGRESS

THE AUTHOR

graduated from the U.S. Naval Academy in 1938 and from the Massachusetts Institute of Technology in 1944. He is an Engineering Duty Officer now serving in the Bureau of Ships as Head of the Hull Design Branch of the Ship Design Division. He is currently a member of the Hull Structure Committee of the Society of Naval Architects and Marine Engineers and Chairman of the Ship Structure Subcommittee of the Ship Structure Committee. Prior assignments have included tours in the Bureau of Ships and at Mare Island and New York Naval Shipyards as well as duty with the Naval Technical Mission to Japan at the end of World War II, and as Chief Engineer of an aircraft carrier during the Korean War.

INTRODUCTION

"SOMETHING VENTURED, something gained. Some people play it by the 'book'. The manager who never argues with percentages . . . the golfer who never tries to clear the water hazard, but plays it short; who always goes around, instead of once in a while shooting straight over the trees. And by their caution they may often win. But they always miss the greatest joys of sport." * Some people may also miss great advances in shipbuilding, quantum jumps in engineering progress, and outstanding technological improvements, if they are ship designers who go strictly by the "book."

How bold is the engineering outlook of the Bureau of Ships? What calculated risks are accepted by the world's foremost ship designer and shipbuilder? How well do they pay off?

Answers to questions such as these cannot be developed from normal cost accounting or management records in a non-profit government activity engaged in the construction of ships for military purposes. Even in private shipbuilding, financial profits realized are not necessarily indicative of vigorous technical approach, of aggressive pioneering, or of a steady assault on engineering frontiers.

An unusual study was recently conducted in the Bureau of Ships for the purpose of examining and assessing the Bureau's approach and philosophy in seeking improvements in ship performance. The study was a frank and candid self-appraisal—"no punches were pulled." The data collected and the conclusions drawn should be of general interest to all ship designers and builders. It is hoped they will be especially interesting to the operators of U. S. Navy ships, who demand improvements, and to their designers and builders, who seek to satisfy these demands.

The study was divided into examinations of five general areas:

I. Bureau of Ships goals in ship design,
II. The Bureau's technical performance in World War II,
III. Evaluation of recent technical difficulties,
IV. Comparisons with other programs, and
V. Assessment of recent major achievements.

Throughout, the costs of attempted progress were evaluated against the risks accepted. Within the limits of security, the results of the study are presented in this article.

* *Sports Illustrated*, 1958.

I. GOALS

It was found that the goal of the Bureau of Ships has been to attain *maximum progress in ship design in the shortest time possible to the end that Navy ships will remain the best in the world.* The Chief of Naval Operations expressed the philosophy underlying this policy in 1955 when he stated:

"If we are to produce ships in the future which include the best propulsion plants, weapons, control systems and protective features, it is essential that we speed up the development of nuclear power plants, new weapons together with their appurtenances and launching devices, and the development of all electronic devices. Hand in hand with this, imaginative thinking must be exercised in the design of ships to accommodate new weapons and equipment. These two processes must proceed along parallel lines so that weapons and devices are designed for the ships and the ships are designed to take the weapons and devices. These two processes must be so phased that their completions coincide in the period of building a ship."

/s/ ARLEIGH BURKE

In keeping with this guidance, the Bureau's policy has been to incorporate developments into ship designs at the earliest practicable time so that ship lives may have maximum miliary utility, thus:

Figure 1. Incorporating Developments

Research and development of new equipment generally requires about seven years. This is true both for new commercial products, where the span from conception to marketing averages five to eight years, and in Navy research and development programs where the corresponding period from conception to acceptance of a prototype is about the same. The process of creating a new combatant ship averages about 5½ years for budget, design and construction. Successful overlapping of these two lengthy periods is essential in meeting the Bureau's goal. Failure to operate in this manner would result in delivery of ships fitted with obsolescent equipment. Furthermore, backfitting is not only an expensive alternative, but may even be impossible in some cases unless ship design has anticipated the advanced equipment.

This philosophy of shipbuilding involves some risks. "All advance involves some hazard, but the greatest hazard of all is not to advance."* Calculation of risks to insure minimum losses requires sound engineering judgment in research and development, and in ship design where selection of features and equipment is made. It was found that the Bureau of Ships research and development projects enjoy a high degree of success.

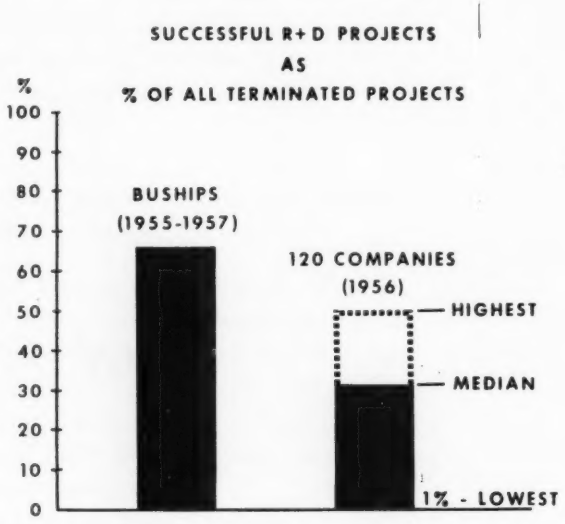


Figure 2. Successful R & D Projects

As may be seen from an examination of Figure 2, during the three-year period, 1955 to 1957, about 67% of the Bureau of Ships projects terminated successfully in comparison with a median in 1956 of 33% for 120 companies.**

Assessment of the Bureau's "batting average" in selection of equipment and features in the ship design stage was found to be more difficult. If an appropriate statistical technique had been available, the effectiveness of the Bureau's risk calculations could have been examined by determining the degree to which projects cluster in the lower right-hand corner of a chart such as Figure 3.

Lacking the necessary mathematical tools for such an analysis, it was decided to make a qualitative approach along these lines for recent efforts. Preliminary to developing these data, however, an historical review of the Bureau's technical performance prior to and during World War II was undertaken.

II. WORLD WAR II PERFORMANCE

It was concluded that *superior ships were available from engineering experimentation and the inevitable troubles that go hand in glove with progress.* An excellent summary of the difficulties experienced by the Bureau of Ships as improvements in ship performance were sought prior to World War II is contained in an article by Hanson Baldwin in the New York *Times* of 4 November 1938. This article, written over twenty years ago, covered in considerable detail difficulties in the 1938 shipbuilding program and a dispute over advancing

* Mr. Glenn Warren, General Electric Corp.

** *Research and Engineering*, June, 1957.

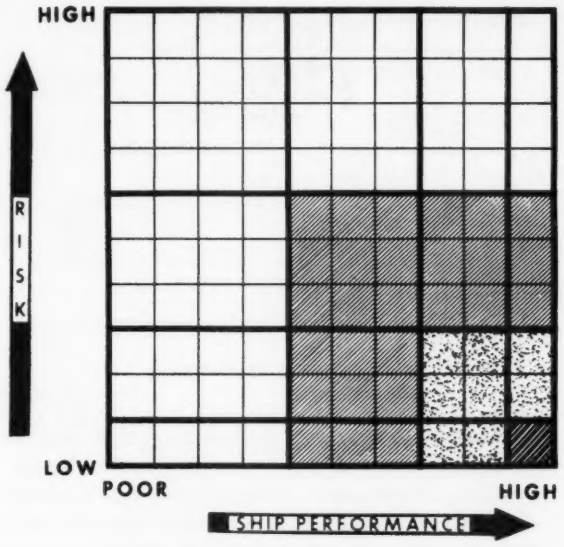


Figure 3. Ship Performance vs. Risk

to high pressure, high temperature (600 psi, 850°F) steam plants in new battleships:

". . . new submarines have had to be re-engined, while a considerable number of brand-new diesel engines built by a private firm have had to be rejected. . .

"The defects have ranged from the cracked stern posts and excessive rolling of the early heavy cruisers to the defective anchor gear of the *Brooklyn* Class. The *Brooklyn* has had breakdown after breakdown, mostly of a minor character, and there have been turbine and condenser troubles in other ships. . .

"Twenty-eight destroyers of the *Mahan* Class have had to have, many of them after completion, very considerable structural and other modifications, including the strengthening of too-thin deck and side plating.

"In the engineering installations of some of the destroyers, which use the same type high pressure, high temperature steam installation proposed for the battleships, cone union joints were used for steam lines, but it was found that these joints could not withstand the pressure . . . in several cases the cone joints had to be replaced at considerable expense by flange joints.

". . . *Enterprise* and *Yorktown*, originally scheduled for completion many months ago, had not yet passed their final acceptance trials. Reduction gearing in both these ships had to be renewed.

"In some ships corrosion-resistant tank steel . . . corroded after installation and had to be replaced. . . .

"But the most serious criticism of many of the new ships concerns first the question of their reliability, and second, their machinery arrangement. . . ."

Mr. Baldwin was, as usual, well informed. It would be easy to add many more items to his list. But, the lessons learned from these difficulties, every one of which stemmed from attempts to improve ship performance, were successfully incorporated in subsequent ship designs. This dearly bought knowledge and experience contributed directly to the outstanding technical performance of our World War II ships.

During World War II, the Bureau of Ships directed the construction of the largest fleet in the history of mankind. Figure 4 gives the dramatic statistics for this achievement.

ITEM	NUMBER	TONNAGE
COMBATANT		
BB	8	320,000
CVL	9	99,000
CV	17	460,700
CVB		
CVE	109	1,165,900
CL	32	292,000
CA	11	149,600
CB	2	55,000
DD	339	680,550
DE	504	651,725
SS	198	302,940
TOTAL COMBATANT	**1,229**	**4,177,415**
MINE CRAFT	869	317,612
PATROL CRAFT	1,802	367,475
AUXILIARIES	1,255	2,781,583
LANDING CRAFT (LARGE)	4,072	2,332,463
LANDING CRAFT (SMALL)	77,000	1,535,777
GRAND TOTAL	**86,927**	**11,512,325**

Figure 4. WORLD WAR II Shipbuilding & Conversion Record, 1942-1945

These ships had vastly greater endurance than those of our Allies or foes and carried larger payloads of armament and planes. They were ruggedly reliable with 60 and 70-day continuous operating periods not unusual. Prolonged shore bombardments severely tested their own shock resistance. The ability to absorb battle damage was proven time and again. Such a record of performance was made possible by vigorous engineering experimentation and the accompanying troubles that Mr. Baldwin had so vividly described in 1938.

III. RECENT DIFFICULTIES

After World War II ship design was accelerated to make major advances instead of small incremental improvements. Scientific and engineering knowledge, which had been accumulated during the war, was not built into those ships which were constructed under large scale production conditions. During the hurried wartime production period, advances were held in abeyance to avoid delays in the production of ships, which had been standardized by classes insofar as practicable. Historically, we know advances must be made in peacetime—not during war. Further, during the war our Allies (including Russia) gained a fairly complete knowledge of the engineering capabilities and technology of our ships. Formal and informal exchanges of information wiped out our 10-15 year lead over the major foreign powers. Bold and progressive action was required to regain our position of technical superiority in warship construction.

Accelerated progress, however, generated problems because of the state of technical knowledge, design deficiencies, or the press of shipbuilding

schedules. In executing the third phase of the study, the most significant of these problems was evaluated. In each case, an assessment was made of the goal that was sought, the risk, performance, and cost of corrective measures. The results of eight analyses follow:

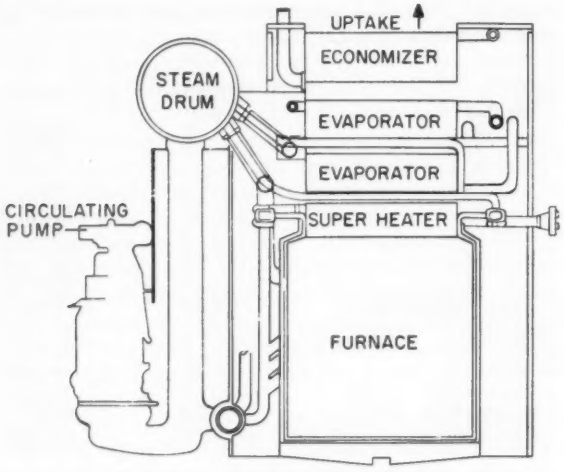


Figure 5. DL2 and 3 Controlled Circulation Boiler

DL 2 and 3 Controlled Circulation Boiler (Figure 5)

GOAL: This type of boiler, embodying the Lamont principle of controlled circulation, was adopted in 1953 for two frigates, DL 2 and 3. In addition to greatly improved flexibility in operation, large reductions in weight and volume were sought.

RISK: Moderate. The Lamont principle had been applied extensively in shore and marine applications, and a test program had been carried out at the Naval Boiler and Turbine Laboratory.

PERFORMANCE: Poor. Operation was critical, and maintainability was difficult. The boilers experienced extensive tube leakage, followed by casing deterioration. While weight and volume reduction goals—15% of weight and 35% of volume—were essentially achieved, high caliber personnel necessary for proper operation are not available.

COST: $7,000,000 for correction of deficiencies and replacement in two ships in 1959.

High Strength Alloy, Steel Shafting

GOAL: Weight saving of over 400 tons in an aircraft carrier, 20% reduction of shaft diameter, and elimination of dependence on the supply of critical nickel needed for the nickel steels then in use.

RISK: Moderate. The material had been applied commercially, and extensive laboratory testing simulating marine environment had been carried out.

PERFORMANCE: One shaft in *Norfolk* (DL 1) failed in 1955. Weakening may have been caused by frettage fatigue cracks at the propeller hub or shaft sleeves.

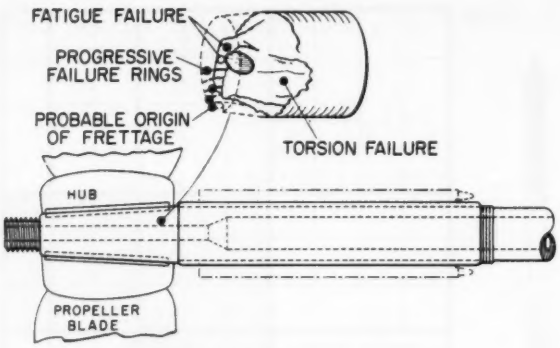


Figure 6. DL 1 Shaft Failure

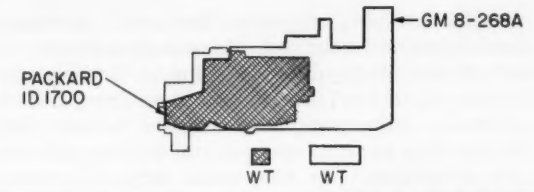
Frettage corrosion is a phenomenon that was not fully understood at the time and is caused by tiny relative movements between mating surfaces. Methods of minimizing conditions conducive to frettage were not yet available. Satisfactory welding repair techniques had not been developed as anticipated.

COST: As a result of this one failure, it was decided to replace "wet" shafting in all 20 aircraft carriers, destroyers, and frigates in which it was fitted. The cost was $13,000,000. However, considerable weight saving was attained by use of the "dry," or inboard alloy shafting. From this experience, cold rolling of shaft tapers is now specified to minimize the effects of frettage corrosion.

Minesweeper Packard Diesel Engines

GOAL: High output, high speed, light weight, nonmagnetic engines for minesweepers.

RISK: (1) Moderate to high, when a development contract was awarded in 1948 to Packard for an experimental unit for emergency generator service in *Timmerman*. Use of lightweight materials such as aluminum for engine blocks and connecting rods involved considerable risk. (2) High, when under pressure of the Korean War in 1950, production contracts for 80 engines of larger capacity were awarded and production initiated before development prototypes were completed. Lightweight materials used in the experimental unit were generally nonmagnetic, and use of this design for the nonmagnetic minesweepers appeared logical. However, instead of building and evaluating one prototype minesweeper as the Bureau had planned, engines had to be ordered on a crash basis for over 200 ships between 1950 and 1953, before the first minesweepers were completed. Hence, orders were placed on Packard and simultaneous ones on General Motors to convert the GM-8-268A and 8-278A to nonmagnetic engines.



	PACKARD	GM
BRAKE HORSEPOWER	600	500
ENGINE RPM	2000	1270
LB/BHP	5.97	18.50
PERCENTAGE NON-MAGNETIC MATERIAL	65%	75%

Figure 7. Minesweeper (Non-Magnetic) Diesel Engines

PERFORMANCE:
As may be seen by comparing data given in Figure 7, the development goals for the Packard engine were attained. However, performance was poor initially. Engines in service developed trouble with deterioration of crankcases, piston seizures and a number of less serious defects, most of which had not shown up in test engines.

COST: $12,500,000 for redesign and procurement of modernized parts for 500 engines, a corrective program which is now essentially completed. Incidentally, simultaneous conversion of the GM-8-268A and 8-278A engines to nonmagnetic ones was highly successful, with 75% substitution attained. Over 700 of these engines are now in use in USN and NATO ships. The corrected Packards, which became a major advance in the state of the art and the successful GM engines, were key items in giving us the best minesweepers in the world.

Non-Paralleling Forced Draft Blowers

GOAL: Development of an alternate source of supply in 1950, weight reduction through higher speeds, and reduction in airborne noise level.

RISK: Moderate. An advance in the state of the art was being sought.

PERFORMANCE: Following approval of the prototype, a prominent manufacturer was the successful bidder in 1955 on 23 shipsworth of blowers, a total of 216 units. The blowers performed excellently, except that during trials of DD 945 in 1958, it became apparent that the blowers could not be made to parallel. This was due to their inability to develop pressure at low flow equal to or greater than the pressures at normal flow. Figure 8 contains load characteristics for the second stages of two forced draft blowers; one that parallels successfully, and one for the non-paralleling one.

COST: $100,000 for shipment of replacement blowers and additional testing at the Naval Boiler and Turbine Laboratory. This cost applies to two ships. Corrective measures, involving installation of turbine blades of new design developed by the manufacturer, have proven successful; and he is bearing the cost. Minor delays in satisfactory

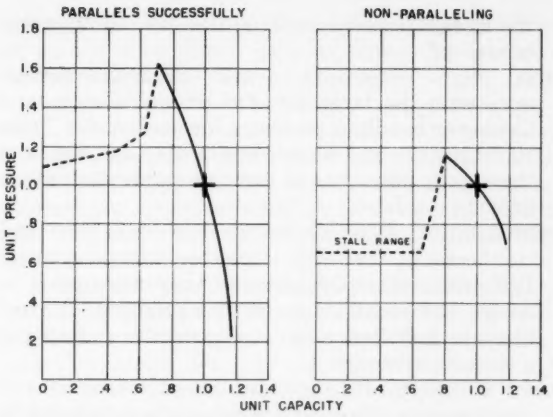


Figure 8. Forced Draft Blower—Capacity vs. Pressure

completion of two destroyers also resulted. Incidentally, a duplicate contract awarded in 1950 to another manufacturer has been highly successful. This is a good example of how contractors may influence performance. Generally, the Bureau attempts to establish a broad industrial base, and the results are not always perfect. Yet, even in the experimental *Timmerman* where the Bureau literally "shot for the moon," there was one completely successful contractor for each type of machinery—generators, gears, turbines, etc. In many instances, there were one successful contractor and two failures, but at least one good one in every case.

SEAWOLF (SSN 575) Reactors

GOAL: To develop a nuclear propulsion system using sodium and having less weight per horsepower and greater fuel economy through the use of superheated steam than could be attained by the *Nautilus* pressurized water-type reactor using saturated steam.

RISK: High. There was no previous marine application.

PERFORMANCE: This ship operated satisfactorily and recently turned in an outstanding performance by setting a new world record of 60 days continuous submergence. Nevertheless, improved efficiency was not realized because of superheater failures which have made necessary permanent bypassing of these superheaters, and the degree of reliability did not prove equal to that of *Nautilus*. Hence, this venture was not as successful as had been anticipated.

COST: $20,000,000 for installation of a *Nautilus* type reactor plant in 1959.

GALVESTON (CLG 3) Missile Handling System

GOAL: To construct the BUSHIPS portion of the first shipboard TALOS missile handling system. The characteristics for this ship did not specify any time or speed requirements, but directed that

the installations be made on the basis of "Spartan economy."

RISK: High. There was no prior shipboard experience with the large TALOS missile. *Boston* and *Canberra* handling problems for the smaller TERRIER missile had been considerably simpler, and there was not time to construct and evaluate a prototype ashore.

PERFORMANCE: Poor. Operation has been slow and cumbersome, involving excessive manual control. Difficulties stemmed basically from attempting to design and construct a complex prototype for immediate installation in a ship while undergoing a major conversion.

COST: $1,000,000 for modifications of magazine and ready service cranes and power carts accomplished early in 1959. These modifications were to meet speed and automatic handling requirements which were generated after the first trials of this prototype installation.

DD 931 and 945 Aluminum Deckhouses

GOAL: To gain the advantages of reduced weight and cost, and eliminate dependence on the fast disappearing art of riveting by using welded aluminum construction with a minimum of expansion joints in lieu of riveted construction and many expansion joints.

RISK: Moderate. Extensive experimentation had preceded this advance. The Bureau had pioneered in the use of aluminum for deckhouses and in developing the welding of aluminum.

PERFORMANCE: Poor initially. During the winter of 1957-1958 many ships reported widespread cracking of aluminum deckhouses. Cracks generally ran athwartships in the heat-affected zones of welds.

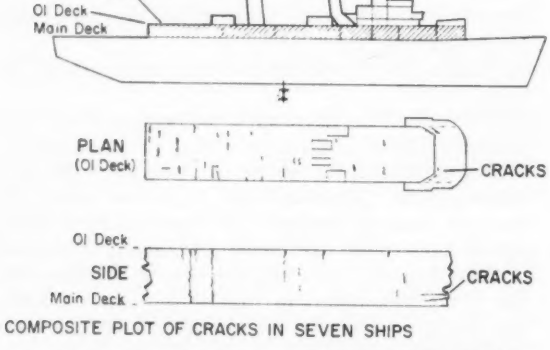


Figure 9. DD 931 & DD 945 Aluminum Deckhouse Failures

They were caused by lower than anticipated fatigue strength of aluminum in these zones, and by large bending stresses generated by the long uninterrupted length of the deckhouse. However, a saving of 45 tons of topside weight was attained. This represented a very significant increase in vital military payload in a type of ship in which weight carrying capacity for ever increasing armament and electronics is at a premium.

COST: $2,300,000 to alter 18 ships by adding additional expansion joints to a total of three, thereby virtually eliminating any stresses in the deckhouses due to ship bending, and by strengthening the attachment to the main deck. Corrective measures have been completed in 12 ships in service and are being incorporated during construction of the remainder. The modifications weigh about 2½ tons per ship so that a net of about 42 tons of topside military payload is being realized in each ship by the use of welded aluminum deckhouses.

Radar Antennas

GOAL: To incorporate maximum electrical characteristics within severe ship installation limitations.

RISK: Moderate to high. The pressure for greater capabilities was intense, and the possibility of decreased mechanical reliability was recognized. The urgency of requirements was generally such that full-scale production had to be initiated before a prototype could be evaluated at sea.

PERFORMANCE: Poor. AN/SPS-6 air search radars had motors burned out and gearing stripped in relatively light winds; the AN/SPS-17/28 air search radars experienced cracking of center weldments caused by center support flexing; AN/SPS-8 air search radars were subjected to excessive gear wear; and AN/SPS-10 surface search radar pedestals were almost completely unreliable with motor gearing and coupling troubles on practically every installation. (See Figure 10)

COST: $4,300,000 for correction of deficiencies in 1,100 radar sets, or an average of about $4,000 per set.

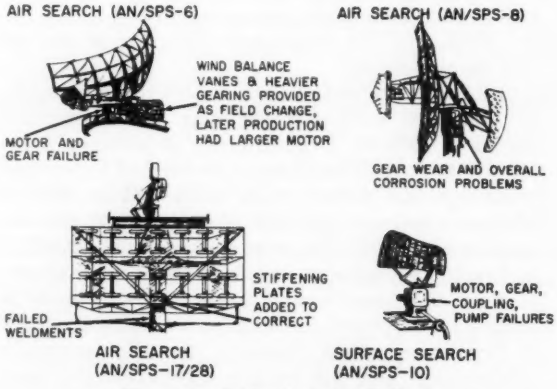

AIR SEARCH (AN/SPS-6)
WIND BALANCE VANES & HEAVIER GEARING PROVIDED AS FIELD CHANGE, LATER PRODUCTION HAD LARGER MOTOR
MOTOR AND GEAR FAILURE
AIR SEARCH (AN/SPS-8)
GEAR WEAR AND OVERALL CORROSION PROBLEMS
STIFFENING PLATES ADDED TO CORRECT
FAILED WELDMENTS
MOTOR, GEAR, COUPLING, PUMP FAILURES
AIR SEARCH (AN/SPS-17/28)
SURFACE SEARCH (AN/SPS-10)

Figure 10. Radar Antenna Failures

IV. COSTS AND COMPARISONS WITH OTHER PROGRAMS

The estimated cost for the major difficulties just reviewed and which stemmed from the Bureau's attempts to advance, totals approximately $60,000,000 over a period of about 8 years. Of course, there were other items of this type. The list includes tur-

bine blade failures in destroyers, reduction gear and feed pump replacements in frigates, difficulties with high speed Fairbanks-Morse diesels in submarines, and many others, which bring the total to about $100,000,000. This sum is certainly not a precise one, but indicates that the Bureau paid about $15,000,000 per year for "hard knocks" as it sought to make engineering progress. The total shipbuilding effort from 1950 to 1958 amounted to roughly $10,000,000,000, so the costs of engineering progress have represented 1% of the total program. This is very low in comparison with other comparable programs.

Some part of what has been called "costs" could be discounted because solid gains have resulted. For example, experience gained with the circulating pumps for the DL 2 and the DL 3 controlled circulation boilers was directly applied in developing high pressure coolant pumps for the *Nautilus* nuclear propulsion plant. Solution of the diesel problems not only resulted in improved and lighter power plants, but advanced the state of the art for the industry as a whole. The forced draft blower episode expanded knowledge of stall characteristics, and made possible rational approaches to similar problems in other ships whose basic phenomena had not been previously understood. How many dollars to discount for lessons learned from unsuccessful projects is not determinate, but certainly those projects were not completely abortive.

Another approach toward evaluating BUSHIPS difficulties in delivering new ships with improved capabilities was made by assessing the effort required for post delivery correction of defects and comparing them with other complex projects. Post delivery costs differ from the 1 per cent cost for "hard knocks" that has just been discussed. They include correction of defective workmanship, elimination of minor design deficiencies, accomplishment of some alterations and incomplete items, as well as correction of difficulties in development items.

MILITARY AIRCRAFT	6 - 10%	
TANKS	6 - 10%	
NAVAL SHIPS	3 - 5%	
CENTRAL POWER PLANTS	$1\frac{1}{4}$ - 3%	
AUTOMOBILES	1 - 2%	PRODUCTION MODELS
MERCHANT SHIPS	$\frac{1}{4}$ - $\frac{1}{2}$%	

Figure 11. Post Delivery Corrections (as % of Total Cost)

The position of "Naval Ships" in this listing is quite favorable. Certainly the ones below it are simpler projects, while the ones above it involve comparable complexity. "Naval Ships" are the lowest among the military projects, where the stimulus for advancement is the most intense.

As part of the effort to develop comparative performance data, information was gathered from other activities, including private industry. It was found, as one might expect, that having difficulties in new engineering ventures is not an exclusive BUSHIPS province, and a few of the examples collected may be of interest.

A few years ago a new turbo-generator in a central power plant in Philadelphia experienced a serious failure in the turbine rotor shaft due to a minor fault in manufacture. The same condition was found in nine other plants, scattered throughout the United States. Replacement of ten turbine rotors cost a prominent manufacturer about $2,500,000. Part of this bill, however, could be discounted because the art of rotor forging was advanced as a result of the lessons learned.

A $400 combination washer-dryer was put on the market in 1954 by a nationally known and well-established appliance manufacturer. A large number of deficiencies, which had not shown up in development and testing, made necessary the recall of the first 60,000 units for extensive redesign and rework.

The introduction of automatic transmissions in automobiles brought a host of problems. Experience with a 2½ ton cargo truck is a case in point. After extensive development by the manufacturer and proof testing, about 60,000 units were sold in 1953. Service use developed many troubles, requiring 40 separate modifications to the automatic transmissions alone. The cost of this corrective effort was about $2,000,000 and took two years to complete.

Continuing in the automotive field, service use in 1954 brought out poor piston ring performance in 100,000 jeeps and made necessary a program for replacing cast iron rings with chrome plated ones to eliminate excessive oil pumping. Similar examples abound in commercial autos. In 1955 a well known manufacturer had to replace cylinder heads of cars in service because the spark plugs were found to be too small. In the same year, it was necessary to replace complete radiators in three popular makes because they were under capacity. It is important to note that the automobile industry subjects its products to rigorous proof testing before marketing, which reaffirms the basic truth that only actual service use, not laboratory or proof testing, can establish the worth of a new product.

V. ACHIEVEMENTS

The final phase of the study that was made to evaluate Bureau of Ships performance in attaining engineering progress was an examination of recent major improvements. It was found that *substantial and significant successes have been attained in design and construction of new naval ships.*

Thirty-one major advances were analyzed as to results attained and calculated risks accepted. Included in this list are eight especially significant ones, which will be described briefly.

Increased Submarine Operating Depths

The 300 ft. depths of 1939 were increased to 400 ft. in World War II. In 1951 they were again increased. Further advances may be expected. The gains were accomplished through the use of high strength steel, whose development was pioneered by BUSHIPS, and by more efficient utilization of structural materials.

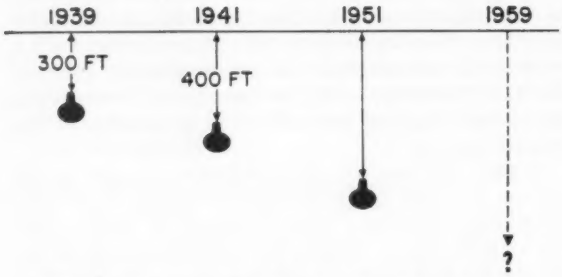


Figure 12. Increased Submarine Operating Depths

Improved Submarine Maneuverability

Turning circles of new submarines have been substantially reduced. This was attained through overriding emphasis on submerged performance, using the latest aerodynamic theories with extensive model testing and analog computer simulation of flight conditions. The recent record breaking speed performance of *Skipjack* was a direct result of the hydrodynamic improvements that were evaluated in *Albacore*.

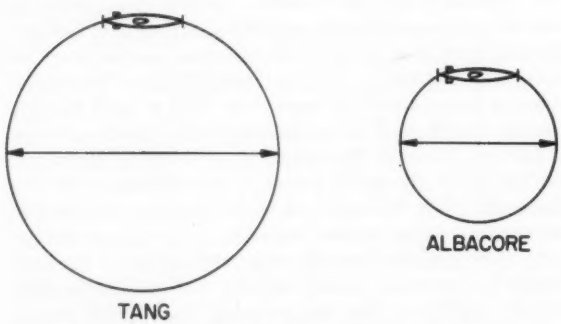


Figure 13. Improved Submarine Maneuverability

Nuclear Propulsion

The submerged endurance of submarines has been increased dramatically by nuclear propulsion. *Skate* is capable of more than one complete submerged circuit around the world, while conventional submarines such as *Tang* are capable of less than 100 miles under similar speed conditions.

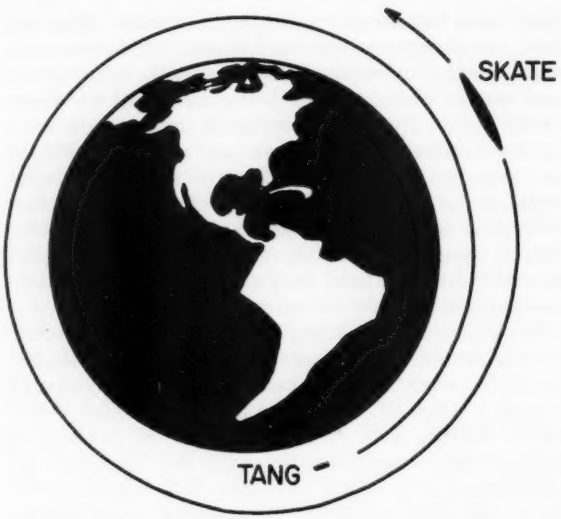


Figure 14. Increased Submarine Submerged Endurance

Improved Atmospheric Habitability of Submarines

Advances in air conditioning equipment and development of CO_2 scrubbers, CO and H_2 removers, oxygen candles, and atmosphere analyzers helped make possible the recent 60-day submergence endurance record of *Seawolf*. With further effort, it should be possible to eliminate atmospheric habitability as a limitation on submarine endurance.

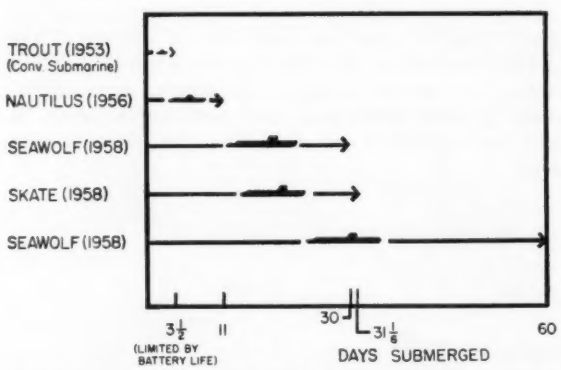


Figure 15. Improved Atmospheric Habitability of Submarines

High Pressure, High Temperature Steam Systems

Advance to 1,200 p.s.i., 950°F steam conditions increased military payloads. *Saratoga* and *Forrestal* are almost identical; but *Saratoga* had 500 tons more payload, which were used to add 1,000 miles in endurance, because she had 1,200 p.s.i., 950°F steam conditions whereas *Forrestal's* were only 600 p.s.i. and 850°F.

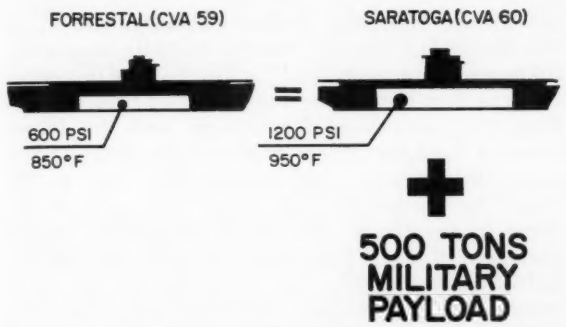


Figure 16. High Pressure High Temperature Steam Systems

High Performance Destroyer Escort

The *Dealey* (DE 1006) Class of escorts is an outstanding ship design, which has won enthusiastic acceptance from the Fleet. She was designed with overriding emphasis on one function—anti-submarine warfare. This ship is simple, rugged and well suited for mass production in an emergency. She is capable of over 25 knots, a considerable margin over the speed called for by her characteristics. Her high freeboard results in a dry ship, and her two rudders give excellent maneuverability despite her single propeller.

Figure 17. High Performance Destroyer Escort

Advanced Aircraft Carriers

Forrestal (CVA 59) represented a milestone in ship design. Certainly she incorporated important features first conceived by others—the angled deck, enclosed bow, and steam catapults. Nevertheless, the successful design and construction of this 76,000 ton ship, the largest combatant in the world, was an engineering achievement of the highest order.

This ship is extraordinarily seaworthy being able to keep the seas in the severest weather conditions. She represents a quantum jump in carrier design, and this venture was not without risk. The full potential of this design will, of course, be realized in *Enterprise*, in which the Navy will have a truly 365-day aircraft carrier. Nuclear propulsion, integrated radars, and other advanced electronic features for analysis of tactical information and control of aircraft will bring this concept to a fuller fruition.

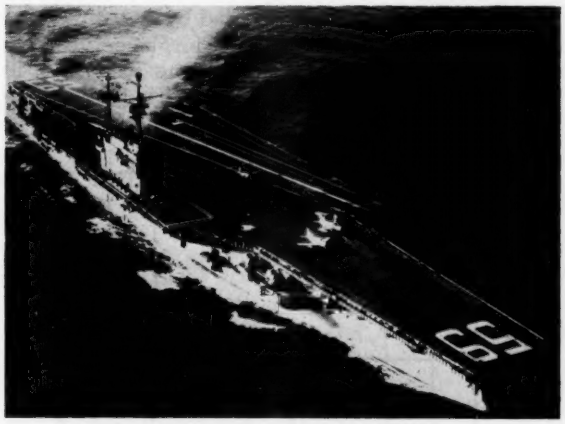
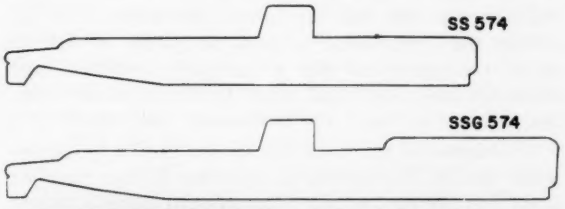


Figure 18. Super Carrier—USS *Forrestal*

Regulus Submarines

Grayback (SSG 574) successfully launched REGULUS II in September 1958. Construction as a conventional submarine had been 80 per cent complete, when BUSHIPS proposed that the design be drastically altered to include the REGULUS I and II capability. By lengthening the SS 574 by 40 ft. on the building ways and redesigning her as the SSG 574, it was possible to incorporate for the first time a new arrangement of hangars and new missile handling and launching equipment. The risk in this undertaking was substantial. The recent cancellation of the REGULUS II missile program and consequent limitation of this design to REGULUS I do not detract from the brightness of this achievement.



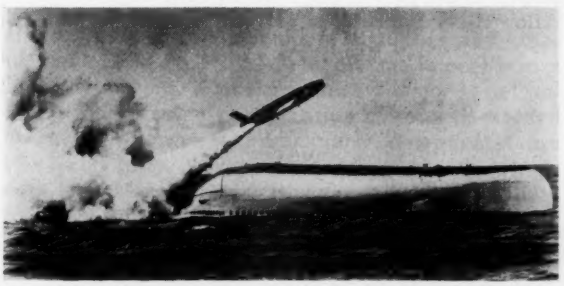


Figure 19. REGULUS II SUBMARINE

Included also in the list of 31 successful projects that were reviewed were such items as ship roll stabilization, gas turbines, ship habitability, minesweeper noise reduction, aircraft elevators, transistorization of electronic equipment, and other significant advances.

The final step in arriving at a general conclusion as to the nature of risks accepted by the Bureau of Ships was to plot on a Ship Performance vs. Risk Chart (Figure 3) the results of the study for 40 high and low performance projects. The results are shown in Figure 20.

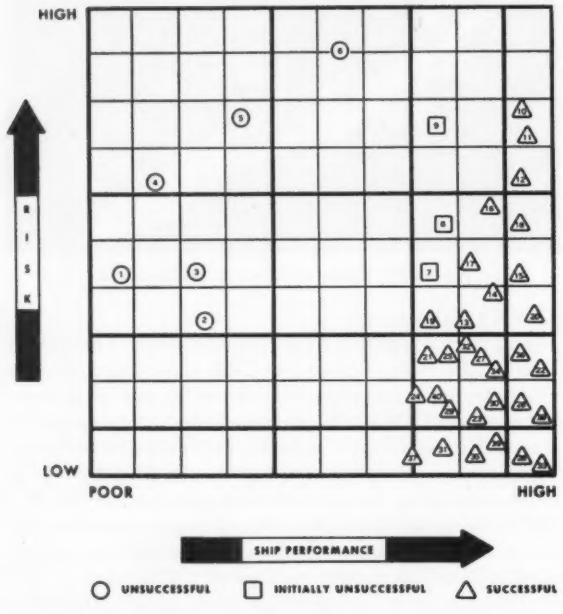


Figure 20. Ship Performance vs. Risk—40 Major Developments

There is no special significance to the number "40" except that all the items are major, and together they represent a good sampling. It will be noted that seven of the 40 projects involved high risks. Of the successful projects, the greatest number fall in the "low" to "moderate" risk zones.

Unsuccessful projects are shown in O's. ① represents the DL Controlled Circulation Boiler problem and ② is the plot of the unsuccessful High Strength Alloy Steel Shafting effort. ⑤ locates the *Galveston* Missile Handling System difficulty, and ⑥ is the *SEAWOLF* Sodium Reactor. Initially unsuccessful projects are plotted in □'s. [7], [8], and [9] represent the Non-Paralleling Forced Draft Blowers, the Destroyer Aluminum Deckhouses and the Minesweeper Packard Diesel Engines. The bulk of the successful projects, △10 through △40, fall in the "low" to "moderate" risk zones, with two of the three in the "high" risk band being △10, which represent Nuclear Propulsion and △12 the REGULUS Submarine. △20, the Super Carrier, is a good example of a successful "moderate" risk. The "low risk" projects bunch together in the lower right hand corner of the chart, and their relative positions in that region are, of course, not susceptible to precise determination. △21 represents Increased Submarine Operating Depths, △39 Improved Submarine Atmospheric Habitability, and △40 the High Performance Destroyer Escort.

SUMMARY

Upon completion of the study, the following conclusions were drawn:

1. Engineering progress is inevitably accompanied by difficulties.
2. The costs of Bureau of Ships difficulties have been relatively low—1% of the total program.
3. The calculated risks taken in new ventures have been generally low to moderate.
4. High risks have been taken when there were prospects of high performance pay-off.
5. In the large majority of cases, attempts to make engineering progress have resulted in good to outstanding performance, at only a slight increase in cost.

The Bureau of Ships is currently directing research and development and shipbuilding programs that exceed any such previous effort in scope and complexity. Billions of dollars, representing a large portion of the nation's investment in security, are committed to them. Revolutionary advances involving nuclear propulsion, guided missiles, and electronics are being boldly incorporated in new designs. As these programs are being shaped, vigorous engineering experimentation based on carefully calculated risks is the keynote, as it was prior to World War II. Some difficulties and setbacks may occur. But, if recent past performance is a sound basis for judgment, good to outstanding over-all performance in naval construction may be confidently expected.

"MECHANICAL ENGINEERING"

EXTERNAL DEPOSITS AND CORROSION IN BOILERS AND GAS TURBINES

ACKNOWLEDGEMENT

This article, written by Bertrand A. Landry, Assistant Technical Director, Battelle Memorial Institute, Columbus, Ohio, was published in the June 1959 issue of "Mechanical Engineering"

THE IMPORTANCE of corrosion and deposits on the fireside of boiler surfaces or in gas turbines is attested by the vast technical literature available. No such proof is needed for design and operating engineers who have seen the problems grow in importance with the use of increasingly higher temperatures and with no diminution in sight for the impurity content of fuels.

Yet when a comparison is made between the amount of ash collected in a boiler or gas turbine, in the form of deposits, and the total amount of ash released during combustion, the conclusion is clear that most of the ash passes through the unit. Under normal conditions, the walls of a boiler or the blades of a turbine are poor ash collectors. The pertinent question becomes: How should boilers or turbines be designed to make them still poorer ash collectors?

MECHANISM OF DEPOSIT GROWTH

For particles to collect on boiler surfaces or blade surfaces, they must first be brought close to the surface itself and be of the proper size. This can be ascribed to physical phenomena involving the reaction of particles to the forces to which they are subjected within the stream of gases passing near the surfaces.

A particle may hit and then rebound from the surface. If it hits or rubs the surface with sufficient force, erosion will result. On the other hand, if the particle is captured physically or chemically by the surface, a deposit is initiated whose growth appears aerodynamically inevitable. Because of high temperatures, reactions can then take place between the various particles deposited and with the gases passing nearby, particularly SO_3 and SO_2. The resulting compounds may then react, by diffusion, with the metal structure on which they are attached and cause corrosion. In boilers, a limit to the growth of the deposit may be reached because of the eventual continuous melting of the outside layer, but the corrosive effect may continue.

In this process of deposit growth, a part can be played by many of the mineral constituents found in fuel impurities, particularly after their conversion to active chemical species during their exposure to combustion or furnace temperatures. So many kinds of these may be released that what happens in a boiler furnace or a gas-turbine combustor is not unlike a spectacular conflagration in a well-stocked chemical laboratory. Particularly detrimental are the compounds of vanadium from fuel oils which, as a liquid deposit, can cause rapid corrosion both in boiler furnaces and in gas turbines.

Low-temperature corrosion of economizers and air heaters is a different problem. It is caused by the condensation of acid on metal surfaces either

through a lowering of the gas temperature to the dew point or by percolation or diffusion of the acid fumes through a porous deposit to the cooler metal underneath. A deposit which may start from a physical deposition of ash may grow through chemical corrosion and promote further corrosion. On the other hand, the use of certain additives, which increase the dust content, appears to be beneficial in adsorbing or neutralizing the acid in spite of the possible disadvantage that this may favor deposits.

Obviously, the study of the causes of deposits, their composition, and their corrosive effect is not simple. Primarily, the impurities in the fuel, the temperatures reached with the combustion system employed, and the aerodynamic behavior of the gases fixed by boiler or turbine design are the imposed variables subject to varying degrees of control. Additional knowledge is needed regarding the interactions between these variables which cause deposits, particularly on the fundamental nature of these interactions. But the problems are so severe that immediate palliatives deserve attention. These include the removal of certain impurities in fuels, the inhibition of the complete oxidation of sulfur, physical, or chemical modification of the metal surfaces, the development of alloys having higher resistance to corrosion, the choice of additive for specific actions, and an answer to the question of whether to clean gases ahead of economizers or air heaters.

REMOVAL OF FUEL IMPURITIES

The variety of mineral constituents found in fuels is large. Although all kinds may not be represented in a given fuel from a certain source, the number of them present is still high. Nearly all of these mineral constituents are probably dissociated by the high temperatures of the flame and of the combustion chamber. On cooling, certain dissociations persist and recombinations take place that give rise to chemical species not originally present. The high-temperature chemistry of these reactions is insufficiently known to permit accurate prediction of the nature and extent of these dissociations and recombinations. Even if more were known, it might not be too helpful because deposition, in its early stages, is probably not due to a chemical reaction with the exposed metal. It can be inferred, however, that sodium, calcium, silicon, and vanadium oxides may each be released as such, and that they play an important role in initial deposition or in direct corrosive attack.

A most important impurity in nearly all fuels is sulfur. At combustion temperatures, the sulfur compounds dissociate or are oxidized to form SO_2 and SO_3. Any free sulfur released reacts with oxygen to form the oxides of sulfur also. Neither of these anhydrides can react appreciably with hot metals below 1200° F, but they can react with the oxides that may have deposited on metal. The oxidation of SO_2 to SO_3 in the presence of oxygen can be catalyzed by hot metals, by active particles in the gas stream, or by active particles after deposition on surfaces. The net result is that the concentration of SO_3 increases as the gases move from burner to economizer. When the temperature is low enough, SO_3 will combine with water to form sulfuric acid. This then becomes available to attack metal in the cooler areas.

Mineral constituents in coal or oil that contain chlorine also are dissociated at high temperatures. The free chlorine formed can immediately react with hydrogen to form hydrochloric acid which, alone, attacks metal at relatively low temperatures but which, in co-operation with sulfuric acid, may be quite corrosive at somewhat higher temperatures. Only one instance has been traced to the chlorine content of the coal in the U. S., but many have been reported in Great Britain.

The presence of these impurities in fuels presents several research problems. Fuel preparation can attenuate some of them, but the complete removal of ash and sulfur is economically infeasible. This does not seem to apply, however, to the NaCl that may be present. Fuel oil may contain an appreciable amount of this salt whose action may be doubly bad: *(a)* In promoting vanadium attack through the formation of sodium vanadates, and *(b)* in promoting low-temperature acid attack because of the formation of HCl.

Until recently, the chlorine content of American coals was not given much attention. Analysis for chlorine is not standard practice, but it would seem desirable for coal users to add this determination. Whenever desirable or indicated, the removal of extraneous NaCl from coal, by washing, should not be technically difficult.

It is not possible to remove vanadium from oil because it is combined chemically with the oil molecules as an organometallic compound. A less costly technique for removing NaCl than washing and centrifuging should be developed, however. Washing at high pressures and temperatures might not lead to the formation of an emulsion and would not be too costly. Fuel-oil additives to neutralize vanadium could be used simultaneously.

One of the most important and perhaps least understood reactions that follows combustion is the group of reactions responsible for the combination of various oxides of vanadium with sodium oxide. A number of compounds can be formed, and some of those found in boiler deposits have no correspondent among x-ray diffraction patterns of known sodium vanadates. The synthesizing of all possible members of this group and cataloguing their behavior under x-ray diffraction should be an important fundamental investigation.

FORMATION OF SO_3

Since it is economically impossible to remove sulfur completely from coal or fuel oil, it is impossible

to prevent the formation of SO_2 during combustion. The oxidation of SO_2 to SO_3 seems to require, however, either the presence of atomic oxygen, which can only occur within the flame, or the subsequent intermediary of a catalyst, but nevertheless occurs in significant proportions.

Some success with oxidation prevention through control of the amount of primary air indicates the desirability of further research.

Most of the SO_3 produced is probably formed catalytically, and information is needed on the nature of the materials in boilers (including deposits) that may serve as catalysts for the oxidation of SO_2.

Since catalysts may be poisoned or so modified as to be ineffective, better knowledge of the specific catalytic effects present would lead to preventive methods. One approach concerns vanadium compounds which can catalyze the oxidation of SO_2. On the other hand, corrosion caused by vanadium can be prevented by the formation of high-temperature-melting compounds by reaction with suitable additives. If this reaction can be made to occur at a high enough temperature, then the vanadium may lose its catalytic properties as well as its corrosive ones. This double-barreled approach deserves attention.

In the absence of a catalyst, the homogeneous rate of oxidation of SO_2 to SO_3 is low, but may be reduced still further by a reaction inhibitor. Although the concept here is rather hazy, research in this direction would be of fundamental value.

Are the sulfates found in boiler deposits formed while still in the gas stream and then deposited, or is sulfate formation limited to the reaction of SO_3 or SO_2 and oxygen with an initial basic deposit such as Na_2O or CaO? An answer would represent an important contribution.

Loss of sensible heat by the gases, as they pass through the various sections of the boiler, results in a lowering of their temperature to the point where SO_3 can react with water to form sulfuric acid. The questions raised by the presence of this acid in the cooler portions of the boiler will be taken up later.

ORIGIN OF DEPOSITS

The existence of high-temperature deposits is, in itself, a sort of mystery. How do they get there and what holds them when they stick?

Physically, most of the solid material released from fuel impurities passes through the boiler or turbine. This is well as otherwise operation could not continue. It is claimed that new boilers often have a lengthy period of immunity from deposits. This can mean that, with time, the smooth surface of metals can be altered to increase its ability to hold particles. There is evidence that, with time, iron alloys, including steel, can build a microscopic needle structure extending away from the surface; this would be a slow process, but one well worth investigating, as it could point out at least two approaches for correction. One would be a search for alloys not possessing this property; another would be a search for metal coatings that would interfere with or prevent this needle-structure formation.

The other mechanisms of initial deposition which have been suggested, such as the wetting of the metal surface by certain bases or salts or the formation of surface-potential forces leading to specific attractions, also need exploration.

One or more of these approaches might answer the question of what makes the particles stick. But how do they get there? The particles released during combustion are of various sizes; chemical reactions that take place alter their sizes. Physically, however, their behavior in the gas stream—that is, whether or not they collide—depends also on their size in relation to the size of gas molecules and on the state of turbulence of the gases. Such collisions can result in a growth or breakup of the particles depending on their physical state. The size of the particle approaching a tube or blade surface may thus have changed considerably from its initial value. Can the range of sizes formed be controlled, perhaps by more rapid cooling of the liquid particles to limit their size or by enforcing a slower cooling rate to increase their size?

The final size of the particle plays an important role when related to the aerodynamic forces that operate when the particle is projected, or hurled, toward a surface and must cross the boundary layer adjacent to the surface to reach the surface. Further studies are needed to prove what are "favorable" and "unfavorable" size ranges for reaching or not reaching the surface.

Once a deposit has been initiated, a substantial change may occur both in the character of the boundary layer and, if the deposit becomes thick enough, in the aerodynamic behavior of the gases passing nearby. Under certain circumstances, this leads to rapid growth of the deposit. It would seem that too much emphasis cannot be placed on arriving at the optimum design of boilers or turbines to minimize deposition through the use of appropriate aerodynamic patterns of flow. Model work can help solve design problems and could include studies to show that the admission of secondary (or tertiary) air at certain critical spots might go far in alleviating the situation.

CORROSION PREVENTION

If deposition is unavoidable, can the corrosive effect of deposits be reduced through the selection of metal surfaces? The field of new-alloy development is so large that there is every assurance that alloys can be found which will have the needed mechanical properties and corrosion resistance. The challenge is one of cost; but the chances remain good, particularly for structural members that are not water or air-cooled.

A promising area for corrosion resistance is the surface coating of metals. This has not been success-

ful, so far, in boiler or turbine applications, but with the variety of techniques and types available it would be surprising if none proved successful.

One aspect of the metallurgical problems associated with deposits and corrosion that must be kept in mind is that of the compatibility of fuel additives with the metals with which they may come in contact.

Because boilers and turbines are normally poor ash collectors, there has been little hesitancy in the use of additives to combat specific nuisances such as vanadium compounds and SO_3 because the boiler and turbine could be relied upon not to retain too much of the additive.

However, this has not always been true, and certain additives, while reducing corrosion effects, have added to deposit problems. Special attention, through the use of the proper research equipment, should be given to the complete behavior of additives so as not to solve one problem at the expense of another.

Although the specific effect of additives seems to have been well explored, further research should probably be done. An important aspect is the method by which they are added to the fuel. For gas turbines, a possible but perhaps costly approach is the development of oil-soluble additives for reaction with vanadium. Water-soluble additives should not be overlooked if they can be shown to be equally effective. The presence of a certain amount of water solution in the fuel oil supplied to a gas turbine is beneficial to the cycle if this water does not interfere with pumping, atomization, and combustion. This is not true of boiler-fired systems, but better distribution of the additive might be achieved in this way, at a slight thermal loss.

As to the introduction of fine solid additives in the gas stream of boiler furnaces, the art seems to be still in relative infancy, and applied research will probably be required to smooth out this operation.

The economizer and air-heater sections of the boiler unit represent special problems. It is here that sulfuric acid is finally formed and can start to be troublesome, along with hydrochloric acid, if present, and if temperatures are low enough.

The removal of acid from the gases, before metals are damaged, can occur either by adsorption within the pores or interstices of otherwise inert dust particles, as often happens in pulverized-coal firing, or by neutralizing the acid by reaction with a basic particle. If the coal fired does not produce enough fine particles having adsorptive properties, then the use of a neutralizing rather than an adsorptive additive seems indicated because of lower cost owing to lower tonnage requirements. Evaluations of available adsorptive and reactive materials in a given locality and of methods of application should be made before a choice is made.

Adsorptive material to remove the acid from the gases before the metal of the air heater is attacked is sometimes naturally provided, and sometimes provided by an additive. There are two other possible solutions to the problem of acid attack, both of which have the advantage that no additive is needed.

One is to develop an inhibited metal surface which resists acid attack while not interfering markedly with heat transfer. It is known that iron compounds can receive this inhibiting treatment. Can it be applied to air heaters?

The other approach, which deserves thorough study, is based on the theory that the presence of a porous deposit on air-heater metal tends to make the temperature of the metal more nearly that of the air being heated than that of the gases supplying the heat. Therefore, acid fumes which have not reached the dew point, while mixed in the gases, can reach it when they have diffused through the deposit to the metal. Corrosion then occurs. Under this theory, it would be advisable to remove all or nearly all of the solids ahead of the air heater or even the economizer. With no solid deposit, there would be little or no corrosion.

Finally, it should be pointed out that the correlation between the determinations of the sulfuric-acid concentration in gases by the dew-point methods and by chemical methods is not good. Many of the results obtained in studying corrosion are not comparable because dew-point determinations were used to measure acid concentration. The fault may lie in using inaccurate dew-point meters. If various hydrates of SO_3 can exist, however, the chemical method may not differentiate between them, whereas their corrosive effect may be different. Fundamental research in this area is strongly indicated.

This listing of possible avenues of research on corrosion and deposits shows that many gaps exist in our present knowledge. Much of the experimental and inferential work that has been done to date has, however, contributed greatly toward the formulation of these questions.

Undoubtedly, several of these approaches will be unrewarding, but others should be successful. There is no doubt, though, that, after a new period of research, other questions will arise. Research results produce additional knowledge, and additional knowledge suggests new research.

HANNS VON SCHERTEL
Translated by DR.-ING. S. F. HOERNER

HYDROFOIL BOATS AS A NEW MEANS OF TRANSPORTATION

ACKNOWLEDGEMENT

The author of this paper, Hanns Freiherr von Schertel, started activities in the field of hydrofoil craft in 1927, building and testing a number of experimental boats between then and 1936. In 1937 von Schertel associated himself with Gotthard Sachsenberg to promote the new type of craft commercially. Development work was undertaken in various towing tanks and in the shipyards of the Gebr. Sachsenberg A.G. at Dessau-Rosslau and in Hamburg-Harburg.

During World War II, a large number of hydrofoil craft was designed, constructed, trial-tested and evaluated for and by the German Navy and the Army's Engineer Corps. Development of these boats, ranging between 4 and 80 tons in displacement weight, and up to 50 knots in speed, came to an end in 1944 when the collapse of Germany became more and more imminent.

Some time after the war, commercial promotion of hydrofoil boats was resumed. Messrs. von Schertel and Sachsenberg associated themselves with a Swiss group to form the Supramar A.G. Mr. von Schertel directs design and development in the offices of that organization in Lucerne (Switzerland). Hydrofoil boats are built to plans and specifications of the Supramar A.G. in a number of countries.

The text (now brought up to date as of May 1959) was originally presented by the author before the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers on October 30, 1958. Translation was done by Dr.-Ing. S. F. Hoerner who is active himself in the field of hydrofoil boats for the U.S. Navy at Gibbs & Cox, Inc. in New York City. The original text is available to interested readers from Supramar A.G. in Lucerne (Switzerland) Friedenstrasse 2.

INTRODUCTION

It has taken a comparatively long period of time (some 50 years) to develop the hydrofoil boat into a type of craft now applied as a "new" means of transportation. One reason for slow progress in the art of "flying" in water, may have rested in certain hydrodynamic problems. Their solution was efficiently approached, however; and a number of experimental hydrofoil boats was eventually produced during World War II. On the basis of practical experience thus gained, high-speed craft of this type were subsequently developed as a means of peaceful transportation. Regular commercial services of reasonable passenger-carrying capacity have been introduced during the last 10 years. Police and similar authorities have also found hydrofoil boats to be particularly suitable in their operations.

Quite a number of papers have been published, dealing with physical principles, hydrodynamic problems and various types of hydrofoil systems. Some of them are listed as bibliographical references at the end of this paper. Little has been reported, however, regarding commercial operation. The present text, therefore, is predominantly devoted to a discussion of the place which hydrofoil craft can fill within the field of modern transportation. Theoretical considerations are presented only to the extent that they seem to be important in the evaluation of operational characteristics.

DEMAND FOR HIGH-SPEED TRANSPORTATION ON WATER

Since the turn of the present century, aircraft have been perfected to such a degree that today more passengers cross the Atlantic by air than by ship. This fact proves that many people prefer speed (saving time) rather than relaxation while traveling. Such preference for speed is also evident in short-distance trips across water, as for example on lakes, bays, rivers and between islands.

After introduction of operational hydrofoil craft, another fact became apparent within the short-distance sector of water-borne transportation. Because of their high cruising speed, up to 3 times as high as that of conventional boat lines, foil-supported craft were found to be even capable of competing with fast land-borne vehicles. Regular hydrofoil-boat services and experimental trips along the coast of Italy have thus demonstrated that these boats (proceeding on straight course) can reach certain destinations in an appreciably shorter time than land-borne vehicles which of necessity follow the more or less jagged line of that coast. Hydrofoil craft may also successfully compete with airplanes over shorter distances, on the basis of considerably lesser cost of operation and maintenance, and in consideration of their point-to-point rather than airport-to-airport performance.

Commuting may also be an application for hydrofoil boats. The time consumed in going to and from work can be very important to employer or company; namely under conditions where compensation must be paid for that time. Such is, for example, the case in off-shore oil-drilling operations, where operators and maintenance crews have to be carried over considerable distances. It is proposed that for such applications, hydrofoil boats are the most suitable means of transportation.

Besides passenger services, there are a number of other uses for hydrofoil craft, where *speed* is of primary concern. Boats in this category are important in military (Navy), rescue (Coast Guard), police and similar operations.

SUITABILITY OF HYDROFOIL BOATS IN COMMERCIAL TRANSPORTATION

Scheduled passenger service by means of water-borne craft becomes commercially interesting: on the basis of speed, under the condition that such a venture can be made profitable, and provided that service can reasonably be maintained in bad weather. The suitability of hydrofoil boats with regard to such conditions is considered as follows.

Speed and Economy of Transportation

Foil-supported craft can be designed for comparatively high speeds, and they can operate at such speeds with reasonable efficiency. This is to say that *at higher Froude numbers,* hydrofoil systems are known to function at drag over weight ratios below those of conventional motorboats. Hydrofoil craft are thus comparatively economical in certain size and speed ranges where other types of water-borne craft cannot very well operate efficiently.

Drag-weight characteristics are shown in Figure 1 where (D/W) values are plotted against Froude number (based on overall hull length) for various types of water-borne craft. Each line represents *minimum* resistance as found in towing-tank tests or as derived from full-scale operation. At higher Froude numbers, V-bottom planing craft are seen to have resistance ratios appreciably lower than those of displacement-type (round-bilge) boats.

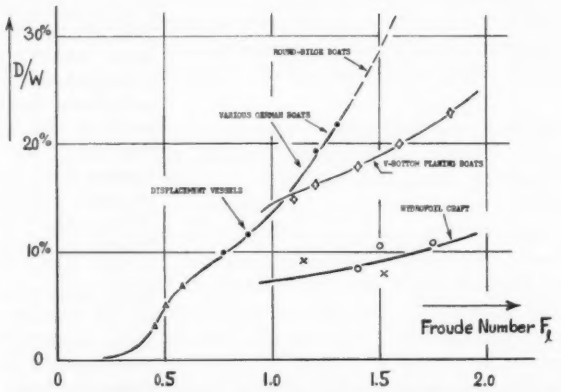


Figure 1. Minimum drag-weight ratios of three different types of boats.

- ● Motorboats from Ref (9)
- ▲ Destroyers from (9) and (16)
- ○ Schertel-Supramar Results
- ◇ German Planing Craft
- × Boats with Fully-Submerged Foils

The line in Figure 1 indicating the minimum drag of hydrofoil craft, represents designs cruising between 30 and 40 knots. The Schertel-Sachsenberg "PT-20" boat, to be described later, is indicated in the graph.

The experimental functions in Figure 1 permit calculation of the performance of a hydrofoil boat in comparison to that of a planing-type craft. On the basis of equal size and equal power, it can thus be found that maximum or crusing speed of the foil-supported craft must be expected to be roughly 50

per cent higher than that of the planing boat. Such prediction was repeatedly confirmed by full-scale trial runs.

The graph (Figure 1) also indicates that the V-bottom planing type of craft requires approximately twice the propelling power of a same-size, same-speed hydrofoil boat. Computation shows that the additional machinery weight required for the planing type has to be compensated by a reduction of the number of passengers to about half of that in the hydrofoil boat, while the expenses for fuel are roughly doubled.

Riding Characteristics in Sea Waves

Considering seakeeping and riding comfort in waves, hydrofoil boats can basically maintain a speed level higher than that of any other water-borne craft comparable in size. Figure 2 is the result of practical experience, approximately indicating the size (height of crest over trough) of sea waves in which hydrofoil boats of Schertel-Sachsenberg design (to be described later) can maintain foil-borne operation. The lower line represents wave amplitudes still permissible when running at full throttle. Wave sizes indicated by the upper line can, on the other hand, be sustained traveling at somewhat reduced speed (but still in foil-borne condition). The graph permits estimation of hull size required for operation in waters where maximum or predominant amplitude of the seaway is known.

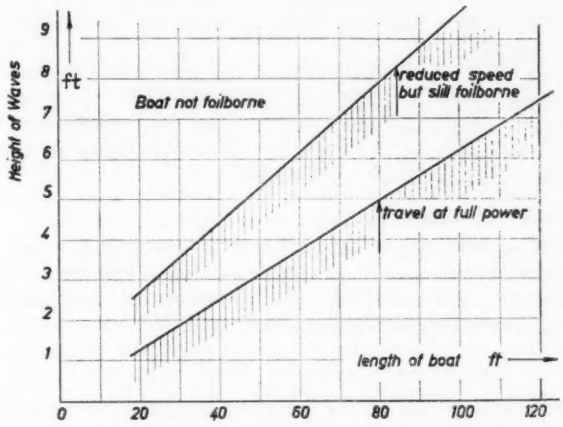


Figure 2. Limits of seaworthiness (average height of waves that can be tolerated) as found in practical operation of Schertel-Sachsenberg-Supramar hydrofoil boats.

Figure 3 is the result of observations made by the captain of a 28-ton hydrofoil boat, operating in the Caribbean Sea. Speeds found sustainable in this case, in the longer (swell-type) waves as found in open (ocean) water, are somewhat higher than those indicated in Figure 2.

The riding comfort aboard water-borne craft is, of course, affected by the motions caused by the seaway encountered. Pitch, heave and roll motions of hydrofoil boats (while "flying") are generally much smaller than those of comparable conventional boats. To obtain some indication of the magnitude of motions in a seaway, a 52 ft. hydrofoil boat was tested in the Baltic Sea, riding at almost 43 knots over waves estimated to be between 2.5 and 3.3 ft. high and between 65 and 80 ft. long. Figure 4 presents average readings from a gyro-controlled instrument. The roll angle is maximum, of course, in beam seas. In comparison to conventional boats, that angle is still small, however; and the angle of pitch is quite small altogether.

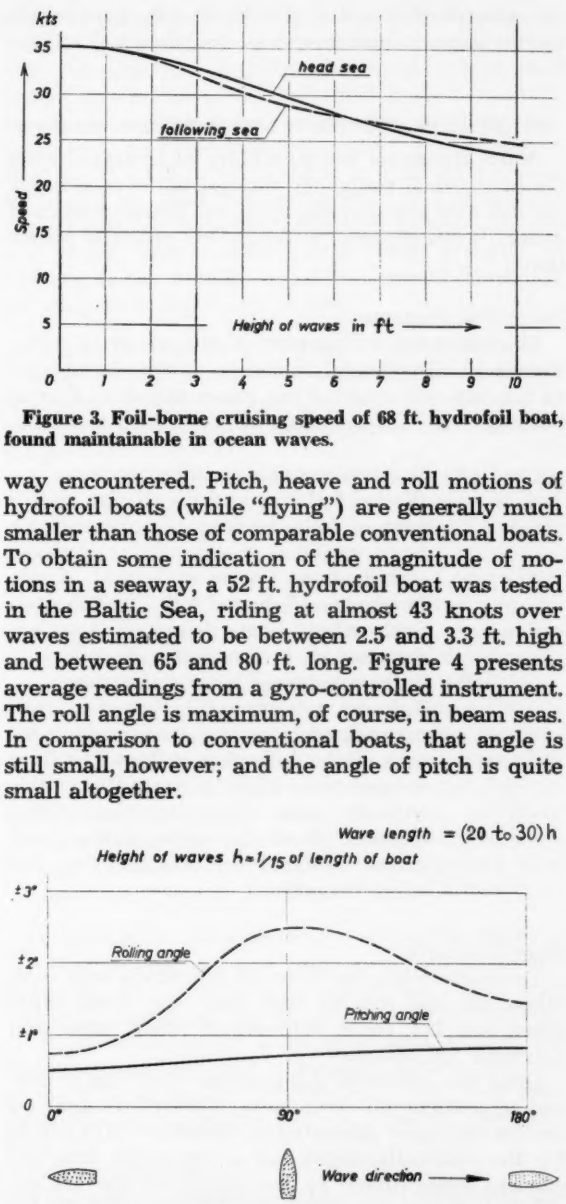


Figure 3. Foil-borne cruising speed of 68 ft. hydrofoil boat, found maintainable in ocean waves.

Figure 4. Mean values of rolling and pitching angles of Schertel-Sachsenberg-Supramar hydrofoil boats observed in sea waves.

Waves in the Wake of Hydrofoil Craft

At higher speeds, conventional motorboats invariably leave behind, in their wake, a wave system of considerable amplitude. The waves may interfere with the operation of other craft and they can do damage to river banks and shore installations. As a consequence, speed of such boats is usually restricted, in narrow waterways. Since hydrofoils develop only comparatively small wave resistance, the disturbance of the water surface in their wake is lit-

tle, accordingly; and it should thus be permissible to run them at higher speeds, on lakes and in harbors.

TECHNICAL CHARACTERISTICS OF HYDROFOIL SYSTEMS

After discussing the suitability of hydrofoil craft for commercial passenger transportation in general, we will now consider the technical characteristics of available foil systems, as they affect practical operation.

Basic Foil Systems

Since it is not the purpose of this report to give a survey on all technical variations designed and tried so far, we will restrict the presentation to that of two types of foil arrangement considered to be basic:

(A) Surface-piercing hydrofoil systems
Wetted foil area and lift change, in this type of foils, by way of submergence. Such variation automatically produces stabilization. The most typical of this family is a V-shaped foil. The Schertel-Sachsenberg boats described later, are designed on the basis of such foils.

(B) Fully-submerged hydrofoil systems
Lift and stability in this type of foils are maintained by way of their angle of attack or the deflection of flaps. Depth of submergence must be controlled in this case by some mechanism, measuring distance above the water surface and giving a signal for changing the foil angle properly.

Drag-Lift Ratio

To compare the two types of hydrofoils with each other, we will assume that they may have equal speed and lift, equal submerged "wing" area and the same foil section.

Drag of a hydrofoil is composed of a "due to lift" and of a frictional component. Theoretical analysis (as for example, presented in reference (9)) yields for the fully-submerged foil a due-to-lift drag coefficient proportional to the square of the lift coefficient. For surface-piercing "V" shaped foils (of the type as used in most of the Schertel-Sachsenberg designs), correlation of experimental results with theoretical methods (as reported in references (7) and (8)) indicates a drag coefficient slightly larger than that for the fully-submerged foil.

In regard to viscous drag originating along the wetted surface of the two foil systems considered, it can be assumed that the struts, needed to support the fully-submerged foil from the hull, may present about the same drag as the surface-piercing ends of the other type of foil. As the speed of a craft is increased (above that of cruising) the wetted area (submergence) of the latter system reduces, however, so that its drag can eventually be less than that of the fully submerged type.

Tests have recently been conducted by Supramar A.G. in Saunders-Roe's towing tank on the Isle of Wight. A pair of hydrofoils, one fully submerged and the other of the surface-piercing type, either one having a projected wetted aspect ratio of A=8.3 and an average submergence ratio of h/c=1.2, produced approximately equal drag-lift ratios in the order of 7 per cent, at a lift coefficient of C_L=0.2. We can thus consider the two basic types of hydrofoils as being equally favorable in regard to resistance at design cruising speed, where lift coefficients are usually between 0.2 and 0.3.

Considering boats utilizing a pair of foils arranged in tandem, theory (mentioned in references (9) and (10)) predicts the possibility of recovering (in the rear foil) at least some fraction of the wave resistance produced by the forward foil. In comparison to a pair of single foils, up to 10 per cent of the total drag originating, can thus be saved by tandem arrangement.

It must be mentioned that the drag ratios quoted above apply to plain hydrofoils, while in complete craft, additional drag components are necessarily caused such as, for example, by an inclined drive shaft and by other appendages.

Behavior in Sea Waves

The behavior of a hydrofoil in sea waves is essentially the result of two functions. The first of these, to be called "wing characteristic", indicates the stabilizing variation (dL/dh); thus:

$$\text{"Z"} = (dL/L_o) / (dh/b_o)$$

where L_o = lift at the intended condition of operation, b_o = wetted span (between piercing points) and h = depth of submergence. In a foil having dihedraled ends, the wetted area "S" changes, of course, as a function of submergence. In the most simple type of foil, the value of the parameter "Z" is then given by $d(S/S_o)/d(h/b_o)$.

Within certain limits, the value of the characteristic "Z" can be influenced, not only by selection of the dihedral angle, but also by suitable variation of foil chord, section chamber and angle of attack. High values of "Z" provide strong stabilization, but rather hard riding over choppy sea waves and vice versa. Proper compromise must be found between stabilization and riding comfort.

The lifting area "S" of a *fully-submerged* hydrofoil does not change as a function of submergence h. The value of "Z" is practically zero, accordingly. To make a craft using such foils stable, variations of lift as a function of "h" are to be provided by proper control of the angle of attack, by means of a mechanical or servo-controlled system. Stabilizing characteristics of this type of foil can then be made to be similar to those of the surface-piercing type described above. In fact, amplification provided

within the control system may be designed or changed as needed. It is also possible to introduce a damping or filtering function in such a manner that the foil does, for example, not react to short and choppy waves; and that it follows the contour of longer waves only so far as to keep the hull clear of the water. It is finally possible to make such variations of response available to the craft's pilot so that stability and behavior can be adjusted to height and type of seaway encountered.

We have considered, so far, the wing characteristic "Z". The second characteristic in a seaway is the reaction to orbital motions, indicated by

$$\text{"W"} = (dC_L/d\alpha)/C_{Lo}$$

where $dC_L/d\alpha$ = lift-curve slope. A high value of "W" means that a foil has the tendency of reacting strongly to orbital velocities in waves. To make a foil tolerant to these motions, it would then be desirable to make the lift-curve slope as small as possible and/or the design lift coefficient C_{Lo} as high as possible. Slope (as a function of foil span) as well as cruising coefficient C_{Lo} are usually dictated by considerations such as drag and/or cavitation and ventilation. Thus, the value of the parameter "W" cannot effectively be reduced; and rigid (fixed-angle-of-attack) hydrofoils are bound to be subjected to the influence of orbital wave motions.

This result is without practical consequence when running against the sea, but undesirable in a following sea. It is found in the latter case, that a maximum reduction of lift (corresponding to the parameter "W") takes place at the time when approaching the crest of a wave. Approaching, on the other hand, the trough of a wave, the orbital motions have the tendency of increasing the foil's lift. Instead of somehow following the contour of the wave, it can thus happen that foil and craft may move "against" the seaway. As a consequence, the hull may then dip into the crests of the waves, so that the speed of the craft is reduced considerably.

The amplitude of orbital motions reduces at a progressive rate, as submergence is increased. A fully-submerged hydrofoil is, as a consequence, exposed to amplitudes which are smaller than the average encountered by a comparable surface-piercing foil. Also, since the maximum lift coefficient (before stalling) of a fully-submerged foil is higher than that of a comparable surface-piercing foil, possibilities of compensating for the influence of orbital motions by variation of the angle of attack must be expected to be very good.

Regarding heaving and pitching motions, a theoretical analysis was recently completed by Mr. de Witt of the engineering staff at Supramar A.G. The combination of those motions in a 95 foot boat is considered in this analysis as they would take place when running at 38 knots in regular following-sea waves.

The analysis shows first that the motions of a rigid surface-piercing tandem system reach maximum amplitudes (both in heave and pitch) at wave lengths in the order of 3 times the length of the craft considered. A fully-submerged (rigid, but somehow altitude-controlled) foil system assumes amplitudes which are considerably smaller than those of the surface-piercing system quoted above. That system was then modified so that the forward foil could be tilted. By giving this foil a sinusoidal angle-of-attack variation, optimized as to amplitude and phase, craft motions were found reduced to average levels roughly equal to those obtained for the fully-submerged foil system.

Conclusions Regarding Practical Application

After discussion of the various characteristics of hydrofoil systems, we can now draw conclusions as to their practical application in passenger transportation.

Boats using the surface-piercing type of hydrofoils, have drag-lift ratios sufficiently low so that their application in high-speed commercial passenger services is justified.

Boats equipped with fully-submerged hydrofoils must be expected to have superior riding and operating qualities in sea waves. The mechanism needed for stabilization of this type of foil system poses certain technical problems, of course.

The only hydrofoil boats so far developed to an operational level and currently used in regular commercial services, make use of the surface-piercing type of hydrofoils. Simplicity of construction, operational reliability and ease of handling, all these characteristics have evidently contributed toward getting foil-borne craft of this type accepted as a commercial means of passenger transportation.

DEVELOPMENT OF OPERATIONAL HYDROFOIL CRAFT

Activities, designs and boats as described in the following, are only those in which the author was and still is engaged. For the duration of World War II, such development work was done within the Gebr. Sachsenberg A.G., a shipyard having facilities at the Elbe River and in Hamburg, and from 1952 on within the Supramar A.G. in Lucerne (Switzerland).

Early experimentation

The author's experimentation with foil-borne vehicles began in 1927. The first successful craft was completed in 1936. One of the early craft, a 3-ton boat, built in 1939, obtained a maximum speed of 38 knots. A 17-ton boat "VS6" was completed in 1941 in the Sachsenberg Boatyard at Dessau-Rosslau. This craft, with a maximum speed of 47.5 knots, was extensively trial-tested in the Baltic Sea; references (1) and (2). The first of a series of six 6.2-ton boats (type "TS") was also completed in 1941. The last of these was equipped with a new-type drive system. The engine, placed in the hull's stern, was connected to a counter-rotating pair of propellers by means of a right-angle bevel-gear drive (see reference (1)).

An 80-ton boat "VS8", launched in 1943, is to this date still the largest ever constructed in the foil-borne field. The 105 ft. long boat (references (1) and (2)) was designed as high-speed cargo carrier for operation between Sicily and Africa. Hull construction was in light alloy. A maximum speed of 40 knots was obtained, using a pair of Mercedes-Benz Diesel engines, with a combined output of 3600 HP. Although the corresponding ratio of 45 HP per ton is considered to be marginal for satisfactory operation, the boat was nevertheless in a position to run at 37 knots against sea waves up to 6 ft. in height. The boat was eventually lost, however, through stranding in a storm caused by engine trouble (but not as a consequence of foil-borne operation).

A 46-ton hydrofoil boat, powered by a 6000 HP engine, was designed to run at a maximum speed of 60 knots. A few days before the scheduled launching, that boat was completely destroyed by bombing from the air. Another, 29 ft. long boat also designed for 60 knots, was tested at speeds up to 52 knots. Completion of the trial runs was made impossible, however, by adverse conditions during the last year of World War II.

Passenger-Carrying Hydrofoil Boats

Some time after the war, commercial application of experience gained during the Schertel-Sachsenberg development as described above, was undertaken by the Supramar A.G. in Switzerland.

The first hydrofoil craft, designed to carry passengers, was completed in 1952. The first boat of this type (see references (1), (2) and (11)) named "PT-10" (with "P" for "passenger", "T" for "transport" and "10" indicating the original design weight in tons) had a total weight of 9.2 tons. A seating capacity for 28 passengers represents a payload fraction of 28 per cent. The "PT-10" was powered by a 500 HP Mercedes-Benz Diesel engine MB-507, installed in the stern of the hull. Reduced-throttle cruising speed was 38 knots. Power applied in this condition corresponds to 13.2 HP for each of the 28 regular passengers.

An interesting quality common to all boats described in this report, is their tolerance as to variations in magnitude and/or location of the payload (passengers and/or cargo). Several craft were repeatedly run with the number of passengers increased by about 50 per cent.

Construction of a 25-ton boat was started in 1953 at the Lürssen Boatyard in Bremen. A hydraulically operated mechanism was provided permitting retraction of the two foils. A pair of flaps were also added to the forward foil. Deflection of these flaps was used in a systematic series of tests, undertaken to improve take-off as well as turning.

A boat similar in size to that in Bremen, but designed to the specifications both of the Registro Italiano Navale and the Germanic Lloyd, was built in 1955 in the Rodriquez Boatyard at Messina. This

Figure 5. Foil-borne "PT-20" boat at cruising speed of approximately 36 knots.

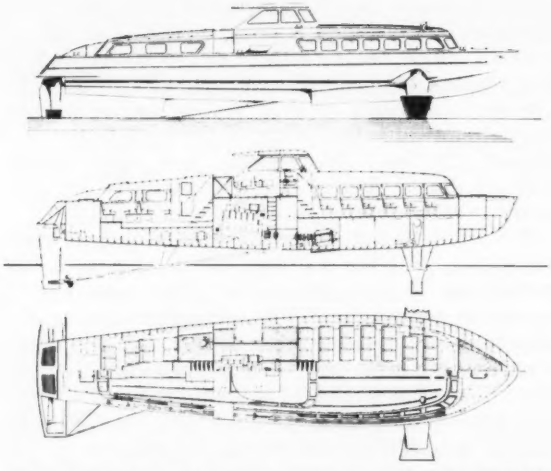


Figure 6. View and general arrangement of the "PT-20" type of hydrofoil boat developed by Supramar A.G. Principal dimensions and performance of this 28-ton craft are listed in the text.

craft was to be the first of a series of very successful boats (see Figures 5 and 6; also references (2), (4), (6) and (11)), seven of which have been put into commercial operation to this date (1959); seven more are under construction. Technical data of this type, designated as "PT-20", are as follows:

Length (overall)	68 ft.
Weight (fully loaded)	28 ton
Payload (passengers)	6.8 ton
Number of passengers	75 —
Maximum power	1350 HP
Maximum speed tested	42 kts.
Cruising speed (at 920 HP)	38 kts.
Range (nautical miles)	270 miles
Max. power per ton weight	48 HP
Max. power per ton payload	135 HP
Cruising, per passenger	12 HP

The light-alloy materials used in building the "PT-

20" hulls are "Al Mg 5" and "Al Mg Si". Watertight compartments are provided below the floor of the passenger deck and in other parts of the hull. The engine installed in the "PT-20" boats is the supercharged 1350 HP Mercedes-Benz Diesel MB-820-Db. For emergency operation (i.e. in case of main engine failure) a 110 HP auxiliary engine is available, located in the stern of the hull.

The general arrangement of the "PT-20" type is shown in Figure 6. The boat is operated and the machinery is controlled from a pilot room placed above the machinery space.

The foils are fabricated from medium steel as shells, welded at the seams. The forward foil can also be tilted within narrow limits by means of a hydraulic ram acting on the cylindrical seam across the hull. It is thus possible to adjust the angle of attack of that foil during operation, to counteract the effects of larger variations in passenger loading and/or to insure optimum behavior in sea waves.

"PT-20" can be considered to be the smallest type of foil-borne craft suitable for passenger-carrying coastal service. In view of its novel and unconventional characteristics, the original boat of this class was first licensed as "experimental" and restricted to operation in a 6-mile zone around the coast of Italy. After supervision and repeated inspection of such service, the Registro Italiano Navale then extended the license, in 1958, to operations within a 20-mile coastal zone.

Technical characteristics reflecting operation of the "PT-20" are presented in Figure 7. Shaft power of the engine was measured during operation by means of a torque meter. The propeller was model-tested, taking into account the influence of shaft inclination. The drag-lift ratio was then derived from net power. This ratio is D/W=8.6 per cent at cruising speed (38 kts) and its minimum is 7.7 per cent at a speed of 34 knots. The corresponding maximum lift-over-drag ratio is W/D=14.3.

Profitable operations with the "PT-20" stirred up sufficient interest in a still larger type of boat, to be used in open water, farther away from the coast,

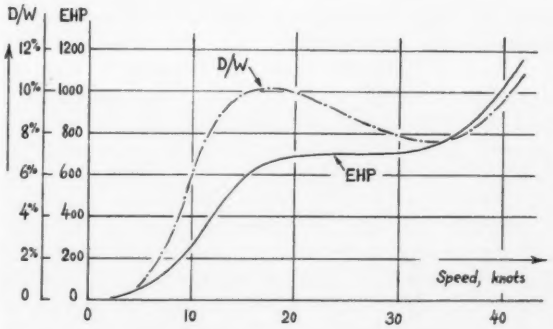


Figure 7. Tested performance of the "PT-20" type; drag/lift ratio (D/W) and effective power (EHP).

suitable for passenger services to and from islands. Construction of the "PT-50" craft (see Figure 8) was, therefore, started in 1958, in the Rodriquez Boatyard at Messina (Italy). Principal data of the boat, launched in April 1959, are as follows:

Length (overall)	89 ft.
Weight (fully loaded)	60 ton
Payload (120 passengers)	14 ton
Combined power of 2 engines	2700 HP
Maximum speed	41 kts
Cruising speed (1700 HP)	38 kts

Passengers are placed below the main deck, in the "PT-50". That deck thus contributes considerably to the strength of the hull, allowing structural weight savings.

The machinery of the 60-tonner is made up of two of the Diesel engines successfully tried over 3 years in the "PT-20" boats. Shafting is simplified as against the small craft, by eliminating the "V"-drive. The lift of the forward foil can be modified by hydraulic operation of a pair of flaps.

During 1958, the Supramar A.G. also worked on the design of a still larger type of hydrofoil boat, proposed to be used in advanced passenger services across open seas. This 130-ton craft is intended to carry a minimum of 250 passengers.

Safety in the Operation of Hydrofoil Boats

High-speed transportation requires rigorous attention to safety precautions. Among the requirements to be met in this respect are stopping and turning.

The time consumed in decelerating the "PT-20" type from full speed to sitting down (bottom of the hull onto water) is between 6 and 7 seconds; and it is less than 25 seconds to a complete stop (using the propeller only after slowing down to small speed). The corresponding distance is in the order of 650 ft.

The response of hydrofoil boats to rudder deflections has always proved to be quick enough to avoid hitting obstacles such as floating debris. The turning radius of the "PT-20" boats is between 350 and 500 ft. when running at cruising speed. That radius reduces, however, to some 100 ft., when lowering speed to 30 knots. In all such turns, the boat banks properly inboard.

It has been argued that hydrofoil boats might be very vulnerable to floating debris. Experience in the operation of such craft has shown, however, that even larger logs of wood are either broken or thrown aside by the concentrated mass of the forward foil; see also page 442 of Vol. I of reference (16).

Under certain conditions, really big obstacles may have to be expected to be found in or under water, such as tree trunks, for example. To avoid major damage to the hull, it is thus advisable to provide shearing points between hull and foil structure.

To investigate the mechanics of collision with

larger obstacles, scale-model tests were undertaken in the towing tank at the Research Institute for Shipbuilding in Berlin. A maximum horizontal hull deceleration of 1 "g" was found in these tests. The time required to break the forward foil off was only 0.1 second, however. This type of deceleration cannot be considered to be dangerous at all. After collision and foil separation, the hull always came down onto the water in essentially horizontal position.

COMMERCIAL EXPERIENCE WITH HYDROFOIL BOATS

First Introduction of Hydrofoil Boats

Soon after the demonstration of the first "PT-10" boat (as reported above), Italian and Swiss government agencies became interested in using this type of craft on Lago Maggiore to carry passengers. In April 1953, such service was licensed by the "Registro Italiano Navale" on one side and the "Eidgenössisches Amt für Verkehr" on behalf of Switzerland. The first scheduled hydrofoil-boat service ever undertaken was subsequently started on May 16 of the same year.

Public interest in the "flying" boat, called "Freccia d'Oro" ("Golden Arrow") was enthusiastic. The distance across Lago Maggiore is 33 nautical miles. The steamer takes 2 hours and 50 minutes to go that distance. The "Freccia d'Oro" was able to cover the same distance in 48 minutes. For comparison, going by automobile around the lake, from one terminal to the other, takes 1½hours. Service was maintained under all conditions of weather, occasionally involving waves of and above 4 ft. in height.

The total distance travelled by the "Freccia d'Oro" in two summer seasons was 27,000 nautical miles. The total number of passengers carried was in the order of 25,000. The ticket price was the equivalent of 8 cents per nautical mile.

Hydrofoil boats have been found useful, not only in passenger-carrying capacity, but in police-type operations as well. A 4-ton craft (described in references (4) and (6)) was built for, and taken over in 1955, by German authorities for the purpose of controlling traffic on the Rhine River. Two more boats of this type were ordered and built to this date.

Boats in Commercial Passenger Services

The first 28-ton craft of the "PT-20" type (see figures (5) and (6)) was completed in 1956. To demonstrate performance, several runs were undertaken along the coast of Italy. On one of them, the distance from Messina to Naples was covered in 5 hours and 40 minutes; corresponding railroad time is 8½ hours. The longest trip undertaken at that time was a 1600 nautical mile round-trip from Italy to Greece. When passing through the Strait of Otranto, the boat met waves in the order of 13 ft. in height.

In August 1956, that first "PT-20" was put into scheduled service, and the craft has now completed over 2½ years of commercial passenger operation between Sicily and the mainland of Italy. Cutting the port-to-port time from Messina to Reggio Calabria to one quarter of that of the conventional ferryboat, the boat makes 11 round trips daily. With a capacity up to 75 passengers, "Freccia del Sole" has carried a record maximum number of some 31,000 people (one-way each) in a single month. The average daily number of passengers is today between 800 and 900. At the end of 1958, that boat had carried a total number of more than 500,000 one-way passengers; and it had completed an accumulated distance of more than 300,000 nautical miles.

Additional boats of the "PT-20" type are operating now, carrying passengers out of Messina to Taormina and Cattania, to the Aeolian Islands and Palermo, and to Gioia Tauro, respectively, on rotating round-trip timetable.

Experience with the "PT-20" shows that the average time consumed in maintenance work (disregarding major machinery overhaul) is, by comparison, approximately 8 hours per 100 hours of running time. It is understood that the time spent in servicing, maintaining and repairing helicopters is between 450 and 750 hours per 100 hours of flying operation.

In July 1958, Italian authorities started regular passenger service on Lago di Garda with another boat of the "PT-20" type. Plans are also underway to introduce scheduled passenger services with two "PT-20" craft each, on two other Italian lakes, Lago di Como and Lago Maggiore, and with one boat in the Trieste area.

Since the beginning of 1959 two "PT-20" are operating between Maracaibo and Cabimas (Venezuela). The two boats together handle an average of nearly 1700 passengers daily, over a distance of approximately 20 miles. The new 60-ton craft "PT-50" (described above) will be used between La Guaira (seaport for Caracas) and Isle Margarita.

Several well-known oil-producing organizations maintain drill towers and pump stations up to some 30 nautical miles offshore in Lake Maracaibo (Venezuela). Since dock to dock commutation of technicians, workers and supervisory personnel is expensive, high-speed transportation is, of course, desirable. To demonstrate the passenger-carrying qualities of hydrofoil craft, an expedition was undertaken, in 1957, to that area. As a consequence, four 28-ton boats, of a special type, were ordered to be used by oil companies on Lake Maracaibo. These are now under construction at the GUSTO shipyard in Holland.

Another "PT-20" boat was shipped to Barbados (British Island in the Lesser Antilles) in May 1958. From there, a 5000 nautical mile round trip was undertaken, to the various islands. The interest of the public in the new type of craft was beyond expectation. During a trip from Barbados to Santa Lucia, the "PT-20" was able to continue in foil-borne con-

dition in waves averaging 16 ft. in height.

As a result of demonstrations in the Caribbean Sea a passenger line was established between Puerto Rico and St. Thomas. A second craft specially adapted to the local conditions, will be commissioned this year (1959) to extend service to other islands.

In tropical waters, there are two circumstances affecting performance. The first is an intensified growth of barnacles on hull bottom and hydrofoil system, eventually increasing drag appreciably. The other is the fact that in hot climates, the engine's power output is reduced as against conditions in more temperate zones by at least 10 per cent.

Economy in Commercial Hydrofoil Operation

The initial cost of construction for foil-borne craft of the type described, is high in comparison to that of conventional motorboats. In spite of larger capital expenditures, commercial operation of hydrofoil craft is quite profitable, however, as explained in the following.

TABLE I—*Tabulation of Purchasing Prices and of Operating Costs of Four Different Means of Transportation Across Water*

	Craft Type	Port-to-Port Speed V	Number of Seats	Price Struct. Weight	Price Per Seat	Operating Costs Passenger-Miles
	—	Knots	—	$/Ton	Dollars	Cents
Passenger Motor Boat	27 Ton	12	92	3600	700	1.4
Hydrofoil Boat	PT-20	36	75	9300	2800	1.6
Commercial Airplane	Convair 440	150	44	43,000	18,600	3.4
Helicopter	Sikorsky S55	72	10	130,000	40,000	12.0

Figure 8. View of the 60-ton "PT-50" hydrofoil boat, designed by Schertel-Supramar, built by Rodriquez Shipyard, Messina (Italy). Launched in April 1959, this boat is the largest hydrofoil craft operating at this time.

Table I presents principal data and expenditures involved in four different modes of transportation, including aircraft (reference (13)). As a common basis, the distance to be covered was assumed to be 100 nautical miles with 2000 hours of operation per year.

The money earned in the commercial operation of a vehicle, is basically proportional to the number of passengers carried as well as to the distance covered during a certain period of time. Since in the services described above, foil-borne craft usually operate at speeds up to 3 times that of conventional boats used in or suitable for the same application, their carrying capacity is potentially up to 3 times as high. A hydrofoil craft can thus be considered to be equal in capacity to a conventional boat up to 3 times its size. Also, on the basis of this carrying factor, amortization of fixed operating expenditures must be expected to proceed three times as fast as in the ordinary type of water-borne craft.

In the last column of the table we have indicated estimated costs of operation per passenger mile, required for the various craft listed.

Because of its time-saving quality, the commercial airplane is evidently an economical means of long-distance transportation. To be sure, an extensive and expensive ground organization is required to make this type of operation possible. Such organization is not available in many places; and it is known that "local" air traffic does not pay well.

As far as short-distance transportation is concerned, the helicopter is technologically a competitor of hydrofoil craft. However, with operating expenses per passenger mile, estimated to be at least 7 times those of the hydrofoil craft, the helicopter (see reference (13)) cannot be considered to be an economical instrument of transportation.

To be conservative, the life time of the hydrofoil craft is assumed to be one-third of that of the ordinary motorboat. Total operating expenditures of the hydrofoil type, as tabulated, are then slightly higher than for the conventional boat. When making this economic comparison, the fact should not be overlooked, however, that the public is generally satisfied to pay higher ticket prices per mile, for a shorter time of passage. In other words, passengers are willing to pay for speed as such. The convenience of frequently scheduled trips is also bound to attract a greater total number of passengers.

To demonstrate economy of operation in hydrofoil boats, analysis is presented, as follows, of actual commercial experience under European conditions. Operation is considered using a pair of "PT-20" boats, *each* having characteristics as follows:

Purchasing price (incl. spare parts)	$240,000
Full passenger capacity	75
Cruising speed at 850 HP	36 kts
Fuel consumption (incl. idling)	141 kg/hr.
Lubrication-oil consumption	3 kg/hr.

Expenditures for fuel are based on 6 cents per kg of Diesel oil and on 53 cents per kg of lubrication oil.—The fixed expenses per year for operation of the 2 boats are:

Wages for a crew of 2 times 4	$21,000
Wages for 3 men ashore	7,000
Maintenance and repair	15,000
Insurance (3.5% on half value)	8,500
Advertising and rents	6,000
Port and pier fees	5,000
Amortization (on basis of 8 years)	60,000
Miscellaneous expenses	4,500
	$127,000

As a result of analysis, it is found that total cost of operation is as follows:

for operation per boat hours per year	Operating Cost / total nautical miles	cost/passenger miles (100 per cent load factor)
1000	$2.04	2.7¢
1500	$1.45	1.9¢
2000	$1.16	1.6¢
2500	$1.00	1.3¢

As a function of ticket price (in cents per nautical mile) and taking into account the average degree to which the seating capacity of the boats is filled, Figure 9 indicates the yearly net return (per cent of capital investment) to be expected in the type of operation defined above. As a function of three parameters, the graph enables one to anticipate whether or not commercial application of hydrofoil boats would be profitable under given or estimated local conditions.

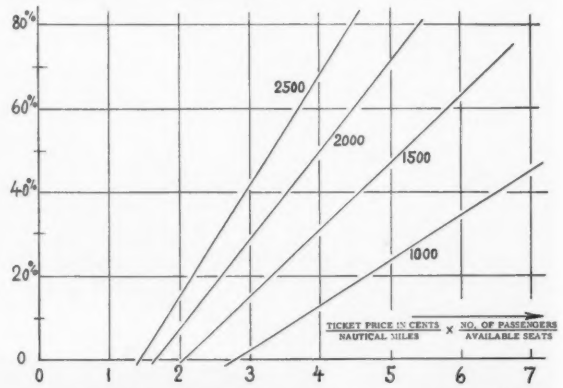


Figure 9. Profit (yearly net return in % of capital invested) to be expected in commercial operation of passenger-carrying hydrofoil boats, under conditions as explained in the text. The numbers assigned to the lines indicate yearly operating hours per boat.

Assuming a ticket price of 8 cents per nautical mile and an average number of passengers corresponding to a modest 50 per cent of capacity, a value of 8 times 0.5=4.0 is obtained for the abscissa in the graph. Assuming further a yearly operating time (port to port) of 1500 hours, the graph yields a net yearly return of somewhat more than 30 per cent. Following now the "1500" line to the point where it intersects the base line of the graph, we find a

limiting ticket-price parameter of slightly more than 2.0. Dividing this value by 8 (cents per passenger mile) we finally obtain the minimum average number of passengers required to avoid economical loss in the operation. This number corresponds to 2/8=25 per cent of the boat's seating capacity, under the conditions as assumed.

As a specific example of a commercial operation, the single-boat ferry service between Messina (Italy) and Reggio Calabria (Sicily) can be mentioned. Average operating expenses are stated to be less than 1 dollar per nautical mile. With only 15 of the 75 seats filled, those expenses can already be recovered.

SUMMARY AND CONCLUSIONS

Technical characteristics of hydrofoil craft are presented insofar as they have an influence upon their application in passenger-carrying capacity (speed, power required, riding comfort).

Two basically different hydrofoil systems are available, the surface-piercing and the fully-submerged type. The former is utilized in all currently operating boats built to Schertel-Sachsenberg-Supramar design. Future application of the fully-submerged type is evidently a question of perfecting a simple and reliable control system.

Development of hydrofoil craft (described in some detail) has reached a level where seaworthy and mechanically reliable passenger-carrying boats of this type are available. Such boats have demonstrated over a number of years that they are decidedly superior in regard to speed sustained in bad weather, to conventional water-borne craft used for the same type of service.

Demand for high-speed water-based transportation is investigated. Economical consideration (including evaluation of air-borne modes of transportation) and several years of practical experience in foil-borne passenger services, prove that hydrofoil boats are well suited for commercial operation.

Design and development work is underway to produce hydrofoil boats of 130 tons of displacement and more, suitable to be used over longer distances and across open seas.

In conclusion, it may be said that all types of "conventional" boats and ships (suitable to be used in "all" conditions of weather and waves) have obviously reached an upper limit as far as speed is concerned. Hydrofoil craft offer the only means now known of extending this limit. Current development of hydrofoil boats, demonstration of their seakeeping characteristics, and profitable commercial operation, lead to the expectation of more extensive application of such craft.

BIBLIOGRAPHICAL REFERENCES

(1) Büller, Hydrofoil Boats, p.119 Yearbook 1952 Schiffbauteschnische Gesellschaft, Hamburg.

(2) von Schertel, Development, Theory and Application of Hydrofoil Boats, VDI Zeitschrift 1956 p.1955.

(3) von Schertel, "Hydrofoil Boats", Chapter in Volume II of "Handbuch der Werften", Verlag Hansa, Hamburg, 1952.

(4) Büller, Practical Application of Hydrofoil Boats, p.299 Yearbook 1956 Schiffbautechnische Gesellschaft, Hamburg.

(5) von Schertel, Hydrofoil Boats in Passenger-Carrying Service, "Schiff und Hafen", September 1955.

(6) Büller, The First Hydrofoil Boat "PT-20" Built to Classification Requirements, Hansa Issue No. 24/25, 1956. See also "Shipping World and World Shipbuilding", 5 December 1956.

(7) Sottorf, Experimental Investigation of Hydrofoils in the Hamburg Towing Tank, FB Rpt of the ZWB (DVL, 1940). Certain results are quoted in (1) (2) (9).

(8) There is a number of unpublished so-called KBR-SF research reports dealing with technical aspects such as drag, stability, turning, propulsion of hydrofoil craft. Such reports are listed and/or principal results are quoted in references such as (1) (2) (9) (16).

(9) Hoerner, "Fluid-Dynamic Drag", published by author, 1958. Hydrodynamic information similar to that in (2) or (7) and hydrofoil results obtained in the United States, are presented in Chapters X and XI of this book.

(10) Buermann-Leehey-Stilwell, Appraisal of Hydrofoil-Supported Craft, Transactions Society NAME 1953 p.242.

(11) von Schertel, "PT-10" and "PT-20", "Schiff and Hafen" 1955 (September issue).

(12) Schäfer, Hydrofoil Boats in Police Service, "Wasserwirtschaft" No. 6, 1958.

(13) Problems in Transportion, Issue No. 9 of Interavia 1952.

(14) Büller, Preliminary Design of Hydrofoil Boats, "Schiffstechnik" Report No. 19, 1956. Translation No. 273 by Taylor Model Basin (1958).

(15) Crewe, Hydrofoil Boat (History and Prospects), Paper No. 5 (March 1958) Institution of Naval Architects (London).

(16) Saunders, Hydrodynamics in Ship Design, 1957 by Soc. Nav. Architects Marine Engineers, N.Y. City.

Photo Courtesy Babcock & Wilcox Co.

Nuclear dry run is practiced by three senior deck officers on the control panel that simulates reactor operation aboard the N.S. *Savannah*. The simulator was developed by Westinghouse as a training aid for the officers and crew of the States Marine Lines, which will operate the first atom-powered merchant ship. Training in technology and operation of the nuclear power plant is being conducted by The Babcock & Wilcox Company, which designed and built the reactor and propulsion systems for the *Savannah*. The actual control panel and nuclear instrumentation was designed and built by the Bailey Meter Company.

ROBERT TAGGART

SPECIAL PURPOSE MARINE PROPULSION SYSTEMS, PART II

THE AUTHOR

is President of Robert Taggart Incorporated, a new firm organized to do contract research and development work in naval architecture, hydrodynamics, acoustics, and propulsion. He received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He has served with the Consolidated Steel Corporation, U.S. Maritime Commission, U.S. Army Transportation Corps, the Naval Research Laboratory, the Bureau of Ships of the Navy Department, and Reed Research, Inc.

EDITOR'S NOTE: *"Special Purpose Marine Propulsion Systems" is one of a series of articles being written by Mr. Taggart and published in the* JOURNAL. *Because of its length this article was split into two parts. The first part will be found on pages 433-447 of the August 1959 issue of the* JOURNAL.

AIR SCREWS

CONSIDERING the centuries during which ships were propelled by sail, it is quite probable that many of the early advocates of mechanical propulsion devices thought of keeping the entire propulsive mechanism above deck. Yet it is also probable that with the very low rotational speed of the first steam engines they soon saw that such a form of ship propulsion was quite impractical. The report of Thomas Jefferson on inspecting an air screw in 1785 in Paris indicated that he felt the inventor would profit by immersing his screw in the water.

Until the development of modern aircraft propulsion techniques, little thought was given to propelling waterborne vehicles by this means. One exception is a series of model experiments conducted by the Reverend C. M. Ramus and William Froude in the early 1870's. They were investigating stepped-bottom planing craft and propelled their models by means of abovewater chemical rockets.

Air propulsion has been used in recent years for experimental purposes to determine the resistance characteristics of full scale ship hulls. A notable example is the series of experiments carried out on the *Lucy Ashton* in Britain in the early 1950's. This ship was fitted with aircraft jet propulsion units which were mounted so that the thrust delivered to the ship could be measured. By this means the full scale resistance-versus-speed curve could be obtained without the effect of any underwater propulsion device, thus aiding in the correlation of model and full scale resistance information.

An interesting experiment has also been conducted recently by the U. S. Navy in connection with the mine defense program. Large turbo-prop engines were installed on the gun mounts of a converted Liberty Ship, and the underwater screw propeller was removed. The gun mounts could be rotated so that the thrust of each propeller could be directed as desired. It was found that by controlling propeller pitch and direction a single man

could maneuver the ship with ease.

These experiments were not conducted with the idea of proving that air screw propulsion had any particular advantages from the standpoint of propulsive efficiency. The very low speed of the ships relative to the outflow velocity of the air jets renders this form of propulsion extremely inefficient. It is only where very high ship velocities are reached with very light hulls that this form of propulsion has any particular advantages. Examples of this are seaplanes and flying boats, which use air screw propulsion for taxiing, and the jet aircraft engine installation on Sir Malcolm Campbell's racing motorboat *Bluebird*.

Yet there are some types of waterborne craft in which air screw propulsion is the optimum solution. In swamp areas any propulsive device which projects below the hull of the boat, or in fact any device which requires water to act upon, is impractical. Swamp areas are infested with tall grasses, roots, floating debris, and mud.

One practical method in areas of this nature is to propel boats with an aircraft screw propeller driven by an aircraft engine mounted on a tripod at the stern. Craft of this type have operated for many years in the Florida Everglades and in the Louisiana Bayou country.

Air screw propulsion is inefficient and requires an expensive fuel. Yet in the particular environment in which these craft are operated the "swamp glider" is extremely effective.

SURFACE PROPELLERS

When screw propellers were first advocated for ship propulsion one of the primary difficulties experienced was that of providing an adequate seal where the propeller shaft penetrated the hull. This was well recognized by many early inventors who often submitted stern tube stuffing gland designs along with their propeller patent applications.

Other inventors dodged the problem by providing chain or pulley drives to the propeller shaft outside the hull. Others designed what is now referred to as a surface propeller.

The surface propeller resembles the conventional screw propeller in appearance except that the major part of the blade disc is above water in the normal running condition. Because of the shock of blade entry the blades are often scimitar shaped to ease the loading as the blade hits the water.

Lack of adequate shaft seals is no longer a basic reason for using surface propellers. Often this type of propulsive device is selected to meet the same operating requirements as those which bring about the use of air screws, that is, operation in shallow, weed-infested waters. Partially submerged screws are readily accessible for freeing of foreign matter and for repair or replacement.

There is one additional advantage to the surface propeller which is frequently employed in high speed planing craft. The reaction to the impact of blade entry into the water is an upward force on the stern of the boat. This force can be utilized to lift the stern, thus reducing the ahead resistance. Although the surface propeller is less efficient than a completely submerged propeller, the gain due to reduced resistance can offset the loss due to lower propulsive efficiency. This sometimes results in an overall improvement in performance.

A notable example of this is the sea sled devised by Albert Hickman. This boat had four screws mounted abreast aft of the transom stern with their lower tips projecting below the line of the bottom. In the at-rest condition the screws were completely submerged but as speed was increased to the planing condition the waterline at the stern was actually at the intersection of the transom and the bottom. A spray shield affixed above the propellers captured additional lift from the spray thrown upward by the emerging blades.

As with other special purpose propulsion devices, the surface propeller can be used to advantage when warranted by functional requirements.

TRACKED VEHICLES

The paddle-track is one of the oldest forms of marine propulsion—in fact it may antedate the paddle-wheel. After a brief surge of interest in this mechanism early in the days of mechanical propulsion development, paddle-tracks faded out of the picture. Now with the amphibious requirements of modern warfare this device has again become a recognized special purpose type of marine propulsion system.

Some amphibians such as Oliver Evans' *Eruktor Amphibolis* in 1804 and the *DUKW* of World War II used separate propulsion devices for movement on land and movement in the water although the driving machinery might be the same for both. But the only practical propulsion device for both land and water of heavy amored vehicles is the paddle-track.

In this device the propelling blades are a compromise between the blades of a paddle-wheel and the treads on a tank or tractor. Cleats or grousers are mounted on an endless moving track usually made up of linked steel plates. One compromise which faces the designer is the need for close spacing of the cleats for adequate support on land and for larger cleat spacing to achieve a good inflow of solid water for propulsion at sea. The result usually seems to favor land operation, since propulsive efficiency in the water is minimal.

The U. S. Navy's LVT (Landing Vehicle, Tracked) is an interesting example of a craft using continuous tracks for propulsion. On land its tracks can drive it at a governed speed of 30 miles an hour, although one Marine vehicle with governor removed is reputed to have sped along at 60 miles an

hour. In the water its speed is very low. Fuel consumption on land is on the order of 6 gallons per mile, while in the water it is 40 gallons per mile.

These are probably among the most inefficient types of waterborne vehicles ever designed, although the modern LVT is a distinct improvement over the earlier models employed in World War II. For a special purpose type of propulsion a certain amount of inefficiency can be tolerated, but it appears that this is one area in which great improvements could be made.

HYDRAULIC JETS

Propulsion by means of a liquid jet emitting from the hull is one of the oldest known forms of mechanically imparting motion to water craft. It was tried in experimental vessels by Toogood and Hayes in 1661, by Allen in 1729, and by Rumsey in 1788. Between 1830 and 1860 in England alone there were at least 35 patent applications for different means of propelling ships with hydraulic jets.

Although the basic principles of these numerous propulsion ideas are the same, there are several different methods of attaining propulsive thrust from the jet. The following examples can be considered characteristic of the proposals of many inventors.

One of the most common types of pump for producing hydraulic jets was the steam driven piston similar to the eighteenth century design of James Rumsey. Water was drawn in at the bow by a vertical reciprocating pump and ejected at the stern. There were some variations of the idea, such as John Reeve's, which proposed in 1857 that the pump piston be driven by a lever from the steam piston so that the water velocity would be increased, thus obtaining a higher ship speed.

In the German hydraulic vessel *Hydromotor* built in 1879, the piston was replaced by a floating block of wood. The wood block rose up and down with the water level in the cylinder, opening and closing the water inlet and discharge ports and the steam inlet and discharge ports.

Another variation of the piston pump was invented by Thomas Carter in 1852. In Carter's design the tube ran along the bottom of the ship and the piston oscillated fore and aft. The piston was a disc which was perpendicular to the tube on the aft stroke and then feathered for the return stroke.

In some of the proposals which employed vertical cylinders the piston was omitted. With the cylinder filled with water and the discharge valve open, steam was admitted to the top of the cylinder. The expansion of the steam forced the water out the stern. The discharge valve was then closed, the suction valve opened, and the steam cut off. The cold water in the cylinder would then condense the steam causing a vacuum which would pull water in from the bow. The cycle was then repeated for as long as the boiler feed water supply held out.

The Archimedian screw pump was employed for jet propulsion in a variety of ways. One of these, invented by Robert Walker in 1843, is illustrated in Figure 18.* Another invented by William Hale in 1836 is shown in Figure 19. The longitudinally oriented screw pump undoubtedly performed more efficiently than the vertical type but its location in the ship indicates a lack of knowledge of the problems of increased frictional resistance due to augmented velocity flow along the hull.

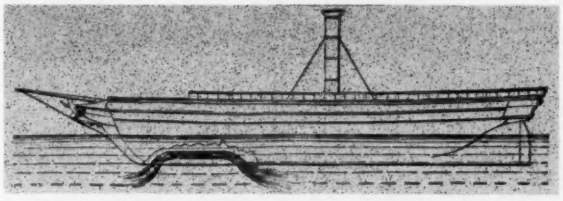


Figure 18. Walker's Jet Propulsion Scheme

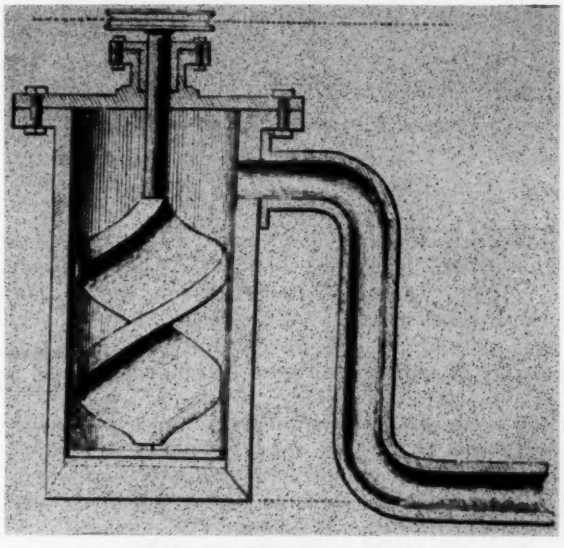


Figure 19. Hale's Screw Pump

A much more efficient form of axial flow pump was patented in 1849 by Henry Bessemer of London. This pump, shown in Figure 20, was a propeller type with a single suction pipe running forward and twin discharges aft. Flow straightening vanes were installed fore and aft of the impeller to attempt to recover some of the losses due to rotation of the fluid. This was a very advanced type of pump design for its time.

The rotary positive displacement pump also received its share of attention. George Alexander Thompson and Joseph Wright of London patented one such device in 1846. As shown in Figure 21 their pump had two geared rotors, with blades and recesses arranged so that one would mesh with the

* Figure numbers are continuous with those in Part I, JASNE, August, 1959.

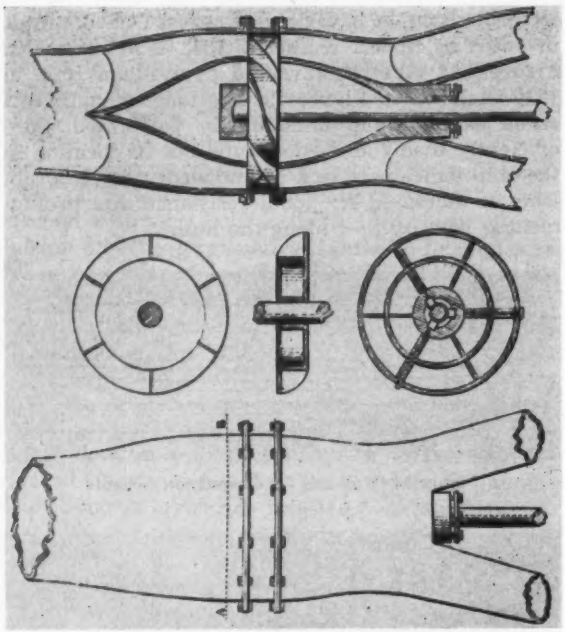


Figure 20. Bessemer's Axial Flow Pump

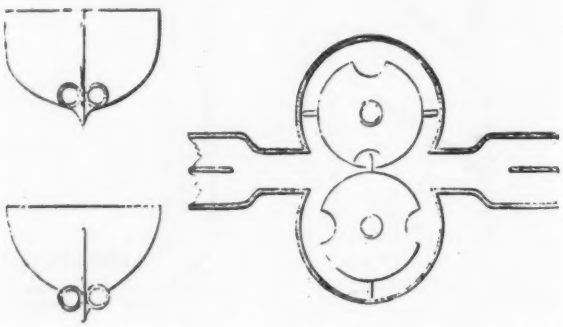


Figure 21. Thompson and Wright's Rotary Pump

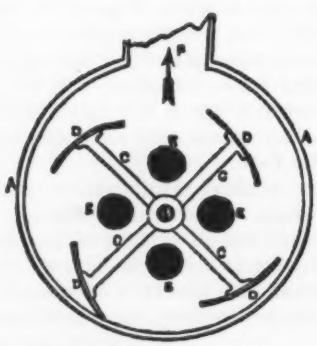


Figure 22. Hale's Centrifugal Pump

other. The resulting pumping action sucked water in from the bow of the ship and discharged it through the stern.

A rather crude form of centrifugal pump was developed by William Hale in 1829 or 1830. He called this a horizontal propeller. As shown in Figure 22, water was pulled in to the center of the pump through four inlet holes in the bottom. The rotating blades generated a centrifugal action and discharged the water through a horizontal pipe at the after end.

A much more sophisticated form of centrifugal pump was designed by John Ruthven in 1849. As shown in Figure 23 water was pulled in from along the keel through a suction sea chest to the center of the pump. The vertical axis rotor, turning at high speed, discharged the water through two tangential outlets from whence it was piped to the sides of the ship. The discharge jets were rotatable elbows which could be turned to give either forward or reverse thrust.

John George Bodmer in 1844 mounted his centrifugal pumps external to the hull proper. Two pumps were installed, one on each side of the deadwood, with their axes vertical. Suction was taken into the center of the pumps at the bottom and discharged through tangential orifices. The pump casings could be rotated so as to provide thrust in any selected direction.

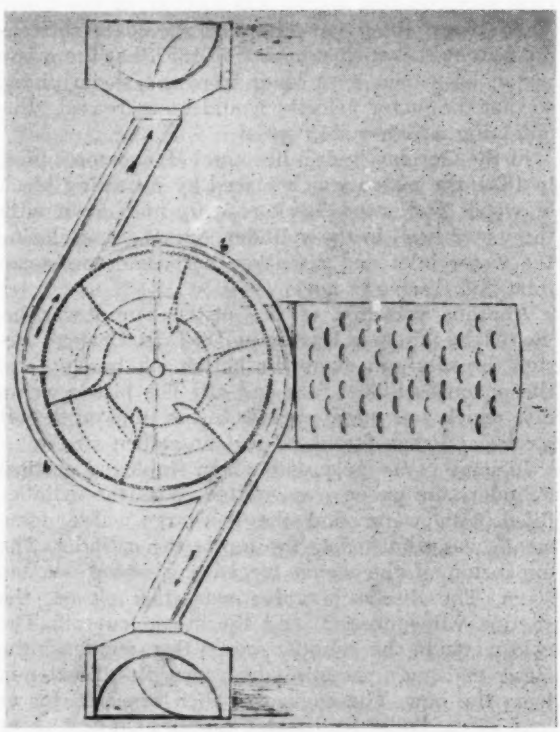


Figure 23. Ruthven's Centrifugal Pump

This was one of the early examples of hydraulic jets being used for steering and maneuvering as well as for propulsion. Another type was described in a London Morning Chronicle in 1840: *"Experiments were tried with a model of an entirely new form of steam vessel, and with every prospect of a successful result. In this remarkable invention there are no paddle-wheels nor external work of any kind. The whole machinery is in the hold of the vessel, where a horizontal wheel is moved by the power of steam, and, acting upon a current of water admitted by the bows and thrown off at the stern, propels the vessel at a rapid rate."* (Reportedly 15 miles per hour) *"By a very simple contrivance of stop-cocks, etc., on the apparatus, the steamer can be turned, retarded, stopped, or have her motion reversed."*

In 1852 Alexandre Hediard patented a jet device where water was sucked into the pump from the bottom of the ship and discharged through a pipe elbow. Rotation of the elbow about the vertical axis provided steering control and reversing.

Toward the end of the nineteenth century hydraulic jet installations were found in many types of watercraft. In 1881 the history of failures with this form of propulsive device was reviewed in Germany with the interesting conclusion that earlier experiments were unsuccesful because *"the propelling force depends on the contact of the surfaces, and not on the sectional area of the flowing mass,"* so a large number of tubes should be used instead of one large tube. In spite of the error of this assumption a ship built on this principle was said to have attained a speed of nine knots. However, no information appeared as to the size of the ship or its power requirements.

In 1888 a steam lifeboat was built by R. and H. Green of Blackwall for the National Lifeboat Institution in Britain. The hydraulic machinery for this craft was built by J. I. Thornycroft and Co. The hydraulic jet was used to prevent racing of a screw propeller in rough water and to keep the propulsion device from being fouled by sand or wreckage. Thornycroft later built several other types of hydraulic jet- and pump jet-propelled boats.

John Ruthven was commissioned by the British Government to install his hydraulic jet in the armored gunboat *Waterwitch* in 1866. The centrifugal pump was fourteen feet in diameter; the discharge nozzles on either side of the stern at the waterline were two feet in diameter.

A similar form of hydraulic jet had been installed some eight years before in a Swedish naval vessel which was designed by a Captain Lilliehook. The machinery and ducting for this ship are shown in Figure 24. Each of the two centrifugal pumps was two feet in diameter. Water was drawn into the pumps from the bottom of the ship and a valving arrangement permitted discharge either forward or aft for ahead or astern operation. The inlet of the pump was subsequently faired into a scoop as

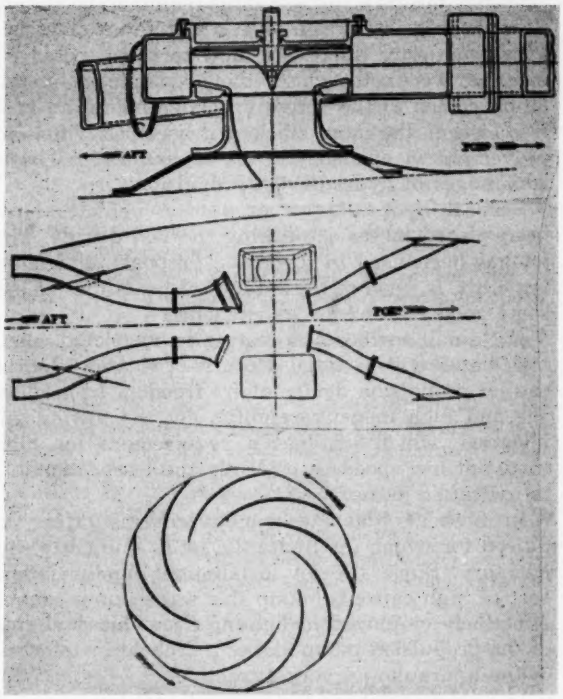


Figure 24. Lilliehook's Hydraulic Jet

shown by the thin lines in the side elevation. This alteration increased the speed from 7.87 to 8.12 knots without any increase in power.

By 1900 the disadvantages inherent in hydraulic jet propulsion were well recognized. In that year in his book on marine propellers Sidney W. Barnaby said:

"There are four characteristics of the centrifugal pump, as applied for the purpose of propelling vessels, which prevent it from competing successfully with the paddle or the screw. These are:

1. *The difficulty of getting the water through the bottom of the vessel and into the pump without checking the velocity which it already has relative to the vessel.*
2. *The necessity of carrying in the vessel all the water acted upon.*
3. *The loss caused by friction of the water in the pipes.*
4. *The loss due to bends in the passages."*

In the twentieth century interest in the hydraulic jet as a means of ship propulsion has continued. This method of propelling a vehicle through water has many advantages. Usually the jet need not protrude below the hull to any pronounced extent and the small protrusion can be made rugged so that damage is unlikely. The jet can readily be used as a steering and maneuvering device which eliminates the need for rudders or other control appendages.

The primary disadvantage of hydraulic jet propulsion is its inherent inefficiency. To increase its

efficiency means going to a large diameter, relatively slow moving jet stream with a minimum of resistance-generating duct-work and tortuous passages. In other words, the closer the hydraulic jet installation comes to the screw propeller operating in a free stream, the more efficient it becomes. Thus improvement in efficiency tends to counter the basic advantages of hydraulic jet propulsion.

Several hydraulic jet propulsion vehicles have been placed in service during the last decade. The jet has been used in towboats, fireboats, and landing craft. In each of these types of boats the jet has some good reasons for its existence.

For small towboats operating in restricted, shallow water with a large amount of floating debris, the jet propulsion device offers freedom from damage and high maneuverability. Yet the towing application, which involves a requirement for high thrust at low speed, is probably the least adaptable to hydraulic jet use.

In fireboats delicate maneuvering is often required for which the hydraulic jet is eminently satisfactory. Since the jet installation involves some sort of high capacity pump this same pump can be effectively employed in fighting fire. This dual role of the propulsion pump makes a fireboat installation of the hydraulic jet very attractive.

In landing craft too the hydraulic jet has a special utilitarian value. To get a boat off the beach the jets, when operating in reverse, can be used to blast a hole in the beach under the boat which greatly simplifies the operation. The good control of the boat in surf which the hydraulic jet offers also is an important reason for propelling landing craft with this type of device.

Recently the Hanley Hydrojet has been used in a small 40-foot towboat installation for the U. S. Army and in fire boats for the U. S. Coast Guard and for service in Australia. And Western Gear

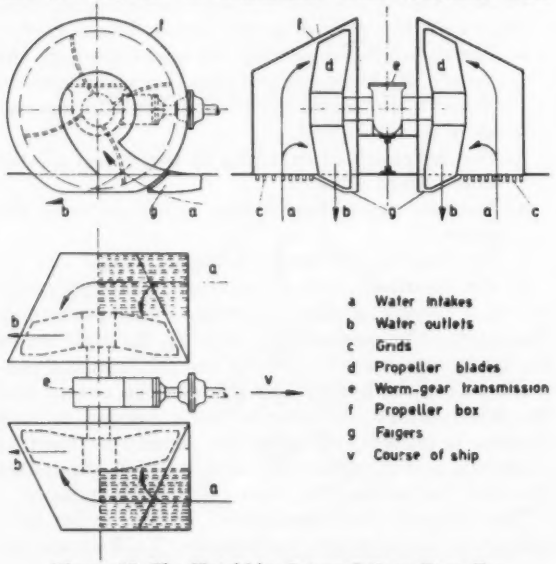


Figure 25. The Hotchkiss Internal Cone Propeller

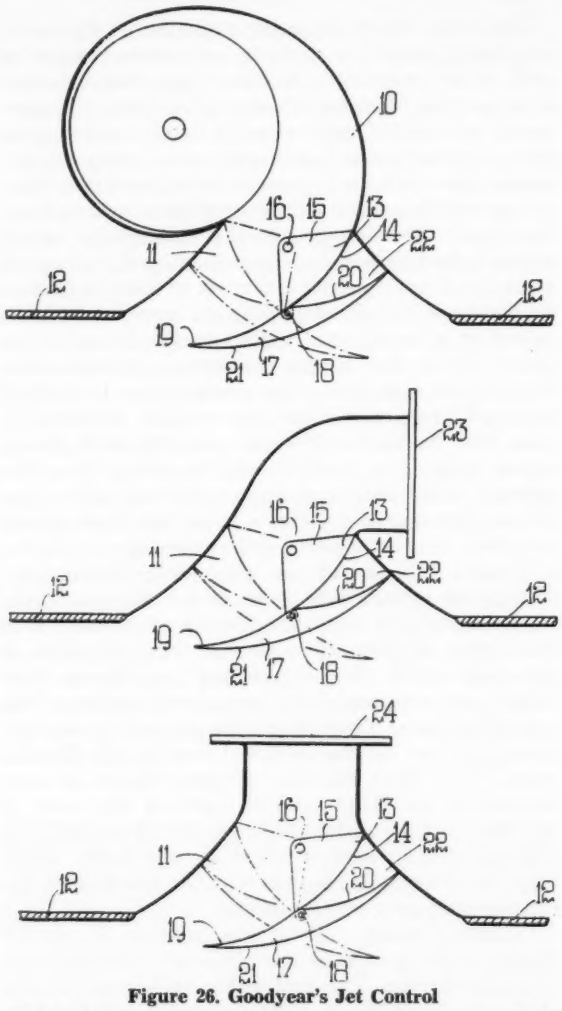


Figure 26. Goodyear's Jet Control

Works has installed a hydraulic jet in a small 36-foot landing craft (LCVP) for the U. S. Navy.

Valid trial data are not available on these boats to evaluate their performance in exact terms of reference. However, from all indications the propulsion system is still very inefficient. It appears that maneuverability and reliability have been emphasized with a corresponding lack of concentration on the improvement of propulsive efficiency.

The Hotchkiss internal-cone propeller shown in Figure 25 is one type of jet pump which is readily available for installation in small craft. Maneuvering control can be retained either by using the flapper valve arrangement patented by J. W. Goodyear, shown in Figure 26, or preferably by rotating the complete drive motor and pump assembly.

The Hotchkiss propeller still enforces a 360 degree change of direction on the water and therefore dissipates a large amount of energy which does not go into the creation of forward thrust. It would appear that it would be feasible to design a practical unit which would rely on straight-through flow, at

least for forward propulsion, which would be much more efficient.

It is interesting to note that although the hydraulic jet has the longest history of development of any of the special purpose propulsion systems mentioned, the improvements which have been made in its performance are not impressive. Here is a device which has many obvious advantages for marine use. It offers a challenge to the ingenuity of inventive minds to make the alterations necessary to optimize its performance.

CONCLUSIONS

It is fairly obvious when reviewing the many different propulsion systems which have been designed for special operating conditions that many of the attractive features of one are almost identical with those of another. The steering screw, the hydraulic jet, the air screw, and the vertical axis propeller all can provide a propulsive thrust with directional control. Similarly both the controlled-pitch propeller and the vertical axis propeller provide a means of using a constant speed, irreversible prime mover to advantage. And the air screw, the paddle-track, the hydraulic jet, and the surface propeller are good devices for operation in shallow, cluttered waters.

The selection of the right propulsive device to suit any given set of marine requirements still poses a problem to the designer. The advantages and disadvantages of each device must be carefully weighed in order that a logical decision can be reached.

However, there has been a wide range of experience gained over a period of many years with both the design and the operation of most of the devices described in this paper. Some, it is true, have not yet reached full maturity and further developments and refinements can be anticipated. But for most propulsion requirements the wealth of experience which has been gained in the past can be used to good advantage in selecting and designing the proper propulsive device.

ACKNOWLEDGMENT

Part of the literature search on which this article is based was done under Contract DA-44-177-TC-409 with the U. S. Army Transportation Corps.

REFERENCES

(Applicable to both Parts I and II)

U. S. Naval Institute, "United States Submarine Operations in World War II," 1949.

Barnaby, Sidney W., "Marine Propellers," London, 1900.

Bourne, J. C., "Treatise on the Screw Propeller," London, 1867.

Dawson, A. J., "Recent Towboat Developments with Particular Reference to Kort Nozzle Propulsion," Trans. SNAME, Vol. 50, 1942

Goldsworthy, E. C. and Brown, A. Betts, "Cycloidal Voith-Schneider Propulsion," Trans. IESS, Vol. 101, Part 3, 1957.

Goodyear, J. W., "Jet Propulsion of Waterborne Vessels," U. S. Patent 2,243,800, 27 May 1941.

Hewins, E. F., "The Vertical Axis Propeller Installation on the Ferry 'Northampton,'" paper presented before the Chesapeake Section, SNAME, 1 April 1950.

Kingsley, Donald M., "Vertical Axis Propellers," paper presented before the Northern California Section, SNAME, 12 December 1957.

Kort, Ludwig, "Combined Device of a Ship's Propeller Enclosed by a Nozzle," U. S. Patent 2,030,375, 11 February 1936.

Kort, Ludwig, "Screw Propeller and Nozzle Ship Propulsion Assembly," U. S. Patent 2,566,525, 4 September 1951.

Macfarlane, Robert, "History of Propellers and Steam Navigation," New York, George P. Putnam, 1851.

Preble, G. H., "Origin and Development of Steam Navigation," Philadelphia, 1883.

Rupp, L. A., "Controllable-Pitch Propellers," Trans. SNAME, Vol. 56, 1948.

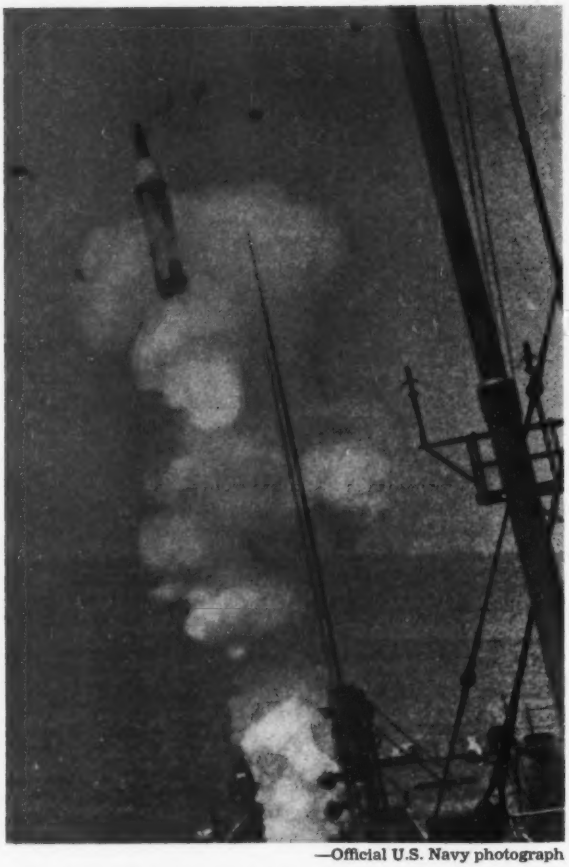
Saunders, H. E., "Hydrodynamics in Ship Design," Vol. I, New York, 1957.

Schoenherr, K. E., "Propulsion and Propellers," *Principles of Naval Architecture*, Vol. II, New York, 1939.

Taggart, Robert, "Beneath the Waves," *Missiles and Rockets*, May 1957.

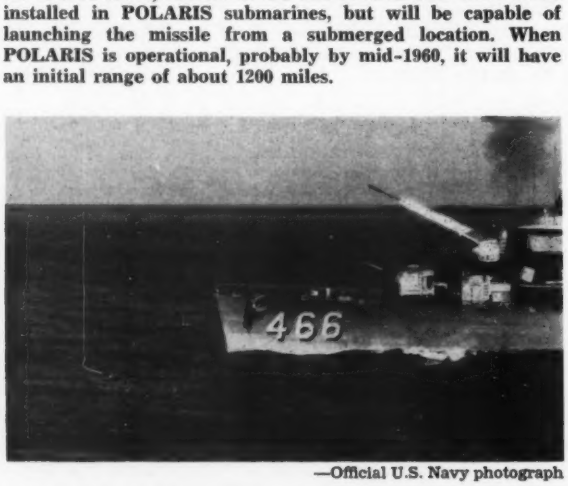
Taggart, Robert, "A History of Propulsion Development," Reed Research, Inc. 1957.

Van Manen, J. D., "Fundamentals of Ship Resistance and Propulsion," *International Shipbuilding Progress*, Vol. 4, No. 30, Feb. 1957.



—Official U.S. Navy photograph

The first POLARIS launching from a ship at sea took place in early September in the Atlantic Missile Range off Cape Canaveral. The missile was fired by compressed air from a tube below the decks of USS *Observation Island*. Hurled into the air from the launching tube, the missile's first-stage engine ignited at an altitude of about 70 feet. The second stage ignited about one minute later and the missile performed as expected over its 700 mile range. Compressed air launch tubes, similar to the one used in this test will be installed in POLARIS submarines, but will be capable of launching the missile from a submerged location. When POLARIS is operational, probably by mid-1960, it will have an initial range of about 1200 miles.

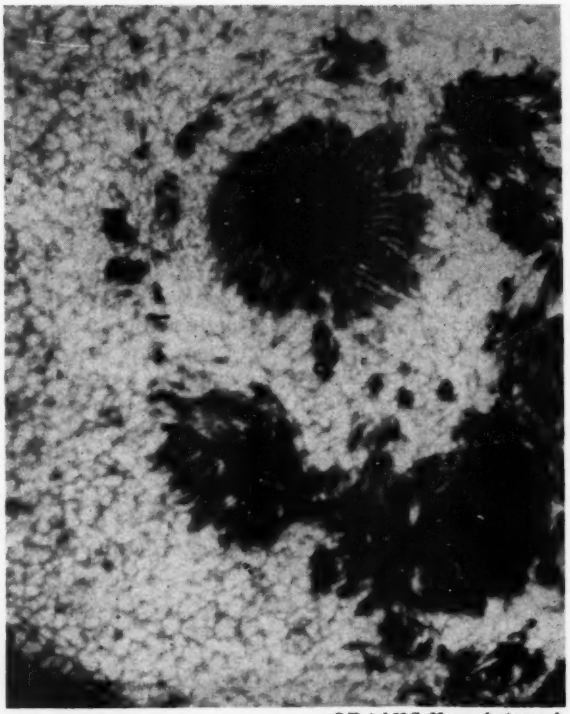


—Official U.S. Navy photograph

Launching a long range anti-submarine rocket, USS *Waller* is shown during ASW exercises of Task Force Alfa in Atlantic waters.

—Official U.S. Navy photograph

This Grumman F9F COUGAR appears to be hurdling over the moon. A part of the air group assigned to USS *Essex*, this aircraft was photographed over the Mediterranean at an altitude of 20,000 feet.



—Official U.S. Navy photograph

An unusual photograph of a sunspot was made from above most of the earth's atmosphere at an altitude of 80,000 feet from a Navy "Stratoscope" balloon. The black spots, or magnetic storms, consist of dark cores of relatively cool gases surrounded by filaments of warmer gases. Major disturbances were produced in radio communications by this solar activity on the day preceding this photograph. The Stratoscope flights are under the sponsorship of the Office of Naval Research and the National Science Foundation.

ROBERT TAGGART

A PROGRAM FOR THE DEVELOPMENT OF AN IMPROVED HYDRAULIC JET PROPULSION DEVICE

THE AUTHOR

(See page 615)

INTRODUCTION

The hydraulic jet is one of the oldest forms of marine propulsion devices. In 1661 Toogood and Hayes described a ship which pumped water through a channel down the centerline, and the first ship propulsion patents in the United States granted to John Fitch and James Rumsey were for hydraulic jets. Throughout the intervening years, various forms of jet propulsion have been tried, but with a notable lack of success from the standpoint of propulsive efficiency.

At the outset it should be recognized that propulsive efficiency of the hydraulic jet will always be less than that of the screw propeller. Yet, there are certain advantages to the hydraulic jet which make it extremely adaptable to many specific marine requirements.

The major advantages of the hydraulic jet are:

1. Steering and maneuvering can be performed by the propulsive mechanism.
2. A simplified control system can be designed to permit operation by relatively untrained personnel.
3. Craft fitted with this propulsive device can operate in shallow and restricted waters.
4. The jet can be reversed for blasting the craft off the beach in landing operations.
5. Water may be drawn into the propulsive device from the boundary layer, and thus the lower velocity flow utilized.
6. Vanes may be readily fitted fore and aft of the impeller to recover rotational energy from the inflow and outflow jet streams.
7. Due to the small mechanical clearances and evenly distributed flow in way of the impeller, vibrations can be minimized.

The major disadvantages of the hydraulic jet are:

1. Necessity of installing inlet grills to prevent debris from entering the impeller.
2. Additional frictional resistance of internal duct surfaces.
3. Difficulty of repairing impeller in small craft due to lack of accessibility.
4. Problems in carrying thrust of a rotating jet assembly over a large area.
5. Difficulty of fitting impeller in nozzle without undue interference with jet stream.
6. Possibility of cavitation occurring at jet discharge.

The purpose of the proposed experimental and design program which follows is to evolve an hydraulic jet propulsion system which retains the advantages of this type of propulsive device with a minimum of the accompanying disadvantages.

DISCUSSION

At the outset, the design of the hull to which the hydraulic jet is to be fitted must be considered a fundamental part of the program. To realize the full advantage of this type of propulsion, the hull interaction must be tailored not only to provide optimum flow conditions but also to house mechanically the propulsive device in the best possible manner.

Furthermore, the design should incorporate all of those features which make the hydraulic jet a desirable propulsive device while minimizing its disadvantages:

1. The jet assembly, including intake and exhaust ducts and impeller, should be capable of being rotated through 360° to utilize the jet for steering and maneuvering. Twin units are desirable to gain maximum control of the craft.
2. If possible no part of the assembly should protrude from the basic hull lines in order to provide for minimum draft of the craft and to prevent damage to the jet assembly.
3. The control system should be as simple as possible to provide a wide range of maneuvering characteristics with untrained personnel at the helm. The prime mover for each jet should be utilized as the power source for turning as well as pumping.
4. The inlet duct should be so designed that water is drawn from the boundary layer over as great a hull area as possible.
5. The length of ducting and the distortion of flow lines should be kept to a minimum to reduce friction drag.
6. The inlet grill should perform additional functions as a scoop and as a series of guide vanes to direct the flow into the impeller.
7. Supports for the impeller shaft should serve as guide vanes to direct the flow at an optimum angle into the impeller and to straighten out the impeller discharge.
8. The clearance between the impeller blades and the housing should be at a minimum to avoid tip losses and cavitation.
9. The impeller assembly should be designed to be as readily removable for maintenance as possible.
10. The bearings supporting the jet assembly should be carefully designed to take thrust as well as to support the weight of the assembly.

DESIGN PROGRAM

The problem of designing a hydraulic jet propelled boat to demonstrate the potential value of this form of propulsive device divides itself into six general areas. These are:

1. Establishment of characteristics
2. Hull design
3. Jet duct design
4. Impeller design
5. Machinery design
6. Control system design

Each of these areas will be treated separately although the interrelation between them is obvious and must necessarily be kept in mind throughout this design program.

Establishment of Characteristics

In order to demonstrate the value of the hydraulic jet, it is necessary first to look at the types of service in which it might prove the most advantageous. Thus, the mission of the craft should be compatible with the hydrodynamic characteristics of the optimum hull and propulsive device for the purpose.

Looking back at the advantages listed for hydraulic jet propelled craft, it can be seen that the mission should be one which requires:

1. High maneuverability
2. Operation in shallow or restricted waters
3. Beaching of the craft

And looking at its disadvantages, the mission should definitely exclude operation over great distances which would require good propulsive efficiency or operation at extremely high speeds for which this type of propulsive device is not suitable.

Matching these characteristics with the marine requirements of the armed forces, it appears that either of two missions might be selected. One of these would be for a small ship-to-shore personnel and cargo boat; the other for a general harbor and river utility boat. Of these two the ship-to-shore personnel and cargo boat appears to be better from the standpoint of establishing more specific design requirements.

In this program, it is not intended to completely specify the mission of the hydraulic jet craft or to go into design details. The program is concerned more with setting up the pattern which should be followed in attacking these problems and with generally defining the scope of the design and experimental program.

The mission of the craft can therefore be stated in general terms which can be subject to modification and refinement as the actual design progresses. The mission is:

1. To transport cargo or personnel from ships at anchor, or underway at low speed, to the beach or to shoreside pier facilities.
2. To carry approximately 5 tons of cargo at a speed of 10 knots.
3. To be capable of off-loading cargo to the beach.
4. To be capable of operation in waters of depth of 3 feet.
5. To be capable of complete grounding on a flat surface without damage to the propulsive device.

This mission determines to some extent the general proportions of the craft, the type of hull, and the powering and maneuvering requirements.

Hull Design

The mission requires that the craft be of shallow draft, of sufficient size to carry the specified cargo weight, and have a bow form adaptable to an off-loading ramp. The beaching requirement dictates that the jet intake scoop be located at the stern and nearly flush with the hull; and the implied maneuvering requirements indicate that a twin-jet design will be needed for maximum control.

Other than the characteristics thus dictated by the mission, the design of the underwater body can be made to adapt itself to the characteristics of the hydraulic jet.

For the sake of economy, the hull form should be simple as long as this principle does not conflict with the optimum employment of the jet. It is equally obvious that the size and proportions should be the minimum compatible with the required capacity. A somewhat box-shaped vessel is therefore indicated with a bow form similar to comparable landing craft presently in use by the armed services. This form provides for a large capacity hold with sufficient shaping of the bottom and keel to give good directional stability characteristics. It allows rugged construction and reasonable proportions for shallow draft operation.

It is the afterbody design which is the main concern in obtaining the maximum effectiveness from the jet. Several methods could be employed to utilize the jet characteristics as shown in Figure 1. All of these methods ignore the once popular idea of pulling in water at the bow and ejecting it at the stern because of the obvious losses due to frictional resistance which would be encountered.

Method (A) has the advantage of simplicity, ease of construction, and ease of control. It is the method which has been employed in one form or another during recent years for several types of craft. It utilizes the slower flow in the boundary layer which can be more efficiently handled by an impeller. It does, however, force the moving fluid into abrupt changes in direction and is therefore limited to smaller diameters of ducting which tends to reduce its efficiency considerably. The exhaust jet is also vulnerable to underwater objects and to grounding.

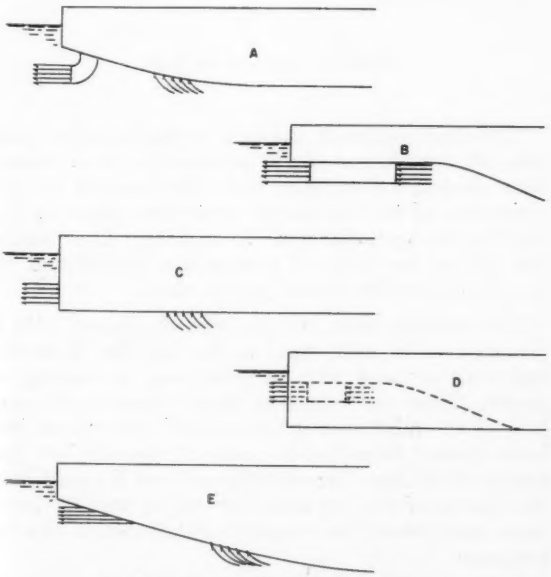


Figure 1. Types of Hydraulic Jets

Method (B) also would have the same advantages as Method (A), but would result in a variable wake entering the impeller. The principal disadvantage of Method (B) is its vulnerability. This method could be termed a ducted propeller rather than a hydraulic jet.

Method (C) has the advantage of complete protection of the jet itself. However, no provision is made for steering the jet, and exhausting it into a zone of complete separation of flow would result in a probable minimum of propulsive efficiency.

Method (D) provides for housing the jet in the protected area of a tunnel stern. Here again, minimum vulnerability would result but no provision is made for maneuvering.

Method (E) appears to hold the greatest promise for the design of a hydraulic jet propulsion device which utilizes the advantages of the jet to a maximum. The device can be completely housed within the hull. The entire assembly can be made to rotate for steering and maneuvering. Boundary layer flow can be fully exploited, and large diameters and nearly straight-through flow will give maximum efficiency. The following discussion will therefore be devoted entirely to this jet design concept.

Although the design of ductwork and of jet rotating mechanisms will be discussed in more detail later, they have an obvious effect on the stern design and therefore must be considered in its development. In general terms the flow to the inlet duct must be unobstructed regardless of the angular position of the assembly, as must the exit flow from the exhaust duct. The stern must be sloped in such a way that the exit flow can be in a horizontal direction at least when the jets are directed for forward thrust. The slope of the stern must also be such that separation will not have occurred at the point where the flow reaches the exhaust jet so that this exit flow may work against solid water.

These two slope criteria are in direct opposition since the greater the slope, the easier it is to discharge the jet horizontally; and the less the slope, the less chance there is of separation occurring. It appears that the compromise between the two must be governed by the separation criterion and therefore a slope of less than 14 degrees is necessary.

As stated earlier, it is desirable that the jet assembly be as short as possible compatible with the requirements for minimum flow distortion within the ductwork. From the standpoint of jet rotation a small diameter of the assembly is also dictated. These two factors, then, will determine the distance

from inlet to discharge ducts. The fore and aft placement of the assembly, however, is a function of the hull design.

To avoid plugging of the inlet scoop when grounding, the assembly should be located as far up the slope as possible. The upper limit would be obviously the water surface. To obtain maximum propulsive thrust it should be located as far below the water surface as possible. Further, since the jet assembly will be relatively heavy, it cannot be moved too far aft. The best compromise between these factors must be worked out in the design stage.

In order that rotating jet assemblies may be used, the hull surface must be completely flat in way of the jets. This condition should also hold across the entire underbody of the stern to provide the best inflow and outflow conditions when the jets are rotated in maneuvering. However, good directional stability characteristics dictate that some lateral area be provided. It thus appears that a centerline skeg should be carried as far aft as feasible without direct interference with the jets regardless of their position of rotation. Outboard skegs, while they would improve directional stability, would affect the flow of water into the jet when operating in very shallow water.

To compensate for the buoyancy lost in the gradually sloping stern, it would seem almost necessary to have very full waterlines aft. Although it would be most desirable to fair the waterlines in gradually to the stern, the other characteristics dictate an almost rectangular set of waterlines. These can be eased somewhat by rounding the bilges and the outboard corners of the stern log.

The transverse position of the jet assemblies is also of importance but is controlled almost entirely by the other design features. For maximum steering control, these assemblies should be as widely separated as possible within the confines of the beam of the craft.

This, then, outlines the general features of the hull design, the factors which govern it, and the design compromises which must be made. More precise design information cannot be delineated until size, proportions, weights, and general arrangements have been decided upon. These are features common to every marine craft design problem, and are therefore not covered in detail in this program.

Jet Duct Design

The design of the inlet and exhaust ducts is probably the most important feature in the development of an efficient hydraulic jet propulsion device. The guiding principles are that the ducts be as short as possible, that the acceleration of the liquid in any direction other than that of the intended thrust be at a minimum, and that the cross sectional area throughout be the maximum possible under the design conditions.

Since hull boundary layer flow is to be utilized within the duct, the inlet opening should cover as great a hull area as possible. This area is limited by the allowable diameter of the jet assembly and by the requirement for minimum acceleration of the liquid which must be pulled within the hull.

Figure 2 shows a method of deriving the contour of the inlet duct based upon simple mathematical curves, i.e., the sinusoid and the ellipse. The intersection of the vertical centerline plane with the top of the duct in the profile view is a half-cyle of a sinusoidal curve which is at a maximum at the impeller position, station 10. The true centerline of the duct and the intersection of the vertical centerline plane with the bottom of the duct are parallel to this first curve.

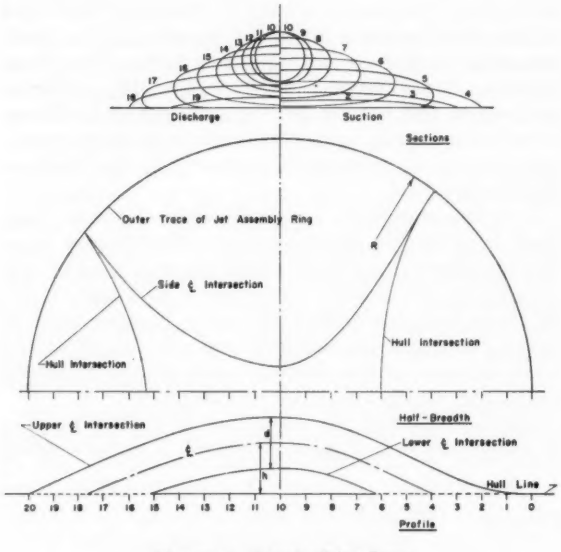


Figure 2. Lines of Jet Duct

The cross section of the duct at the impeller position, station 10, is a circle providing a small clearance around the impeller disc. The trace of the intersection of the horizontal centerline plane of the duct in the sectional view is a straight line joining the hull at the point of intersection established by the true centerline in the profile view.

The sections, then, are a series of ellipses with a constant minor axis equal to the impeller diameter and with a major axis progressively increasing as shown. Thus the complete three dimensional contour of the inlet duct is determined from these few basic curves. Once the diameter of the impeller, the height of the impeller centerline above the hull, and the radius of the jet assembly (d, h, and R) have been established, the complete detail design can be prepared.

The exhaust, or discharge jet, differs somewhat in

design concept. In order to obtain maximum steering control, the exit flow should be confined to a narrower stream. It is also desirable that the flow have an exit direction which is parallel to the keel of the vessel.

The discharge duct employs the same basic curves as the inlet duct. However, only one-fourth cycle of the sinusoidal curve is used as shown in Figure 2. The remainder of the construction is identical to that of the inlet duct. This construction will result in the discharge jet leaving the hull at a fixed angle with a sharp break in the duct wall at the hull intersection. This will cause separation of the flow at that point and prevent it from following the hull contour. In this way, the maximum thrust effort will be obtained. The addition of a small lip on the after side of the duct external to the hull may be desirable for this purpose.

In order to prevent damaging debris from entering the intake duct, a grill work is required. This grill can be designed so as to aid in altering the direction of the flow into the duct. The general arrangement of the grill is shown in Figure 3. Details of the contour of deflecting elements for minimum energy loss can be similar to those developed for propeller test tunnels.

The basic angle of the grill elements should be parallel to the upper and lower centerlines of the duct. However, pitching the port and starboard sections of the grill about one degree to either side of this angle can give the flow an additional rotational component which will direct it into the impeller in such a manner that a slight increase in efficiency will be gained.

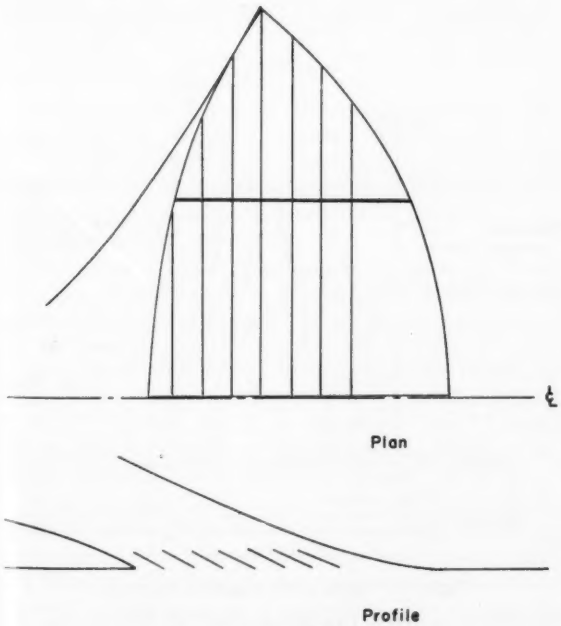


Figure 3. Intake Scoop Grill

The discharge duct requires no grill for protection. It may, however, be desirable to incorporate a few reflector elements to direct the stream at the optimum angle for maximum thrust.

Impeller Design

The type of impeller which appears the most desirable is a simple propeller type device supported on a vertical shaft and driven through a bevel gear.

As to general hydrodynamic characteristics, the fairing containing the bevel gears and shafts should be as small as possible, as should the impeller hub. The fairings which support the impeller fore and aft should also act as contra-vanes to guide the flow into the impeller at the optimum angle and to straighten out the flow aft of the impeller.

The flow approaching the impeller assembly should be uniform across the duct with a slight rotary motion. The velocity profiles across the duct and in the rotational direction will be similar to those shown in Figure 4A. As the flow passes the impeller hub, there will be a corresponding increase in both velocity vectors as shown in Figure 4B.

The impeller blades can thus be designed with a constant pitch from root to tip and with constant lift of the sections except for a slight relief at the root and at the tip. This lift relief can be gained by modification of the hydrofoil characteristics of the blade sections rather than by altering the section length. Strength considerations would imply a thickening of the blade at the root and a thinning of the blade at the tip to accomplish this purpose.

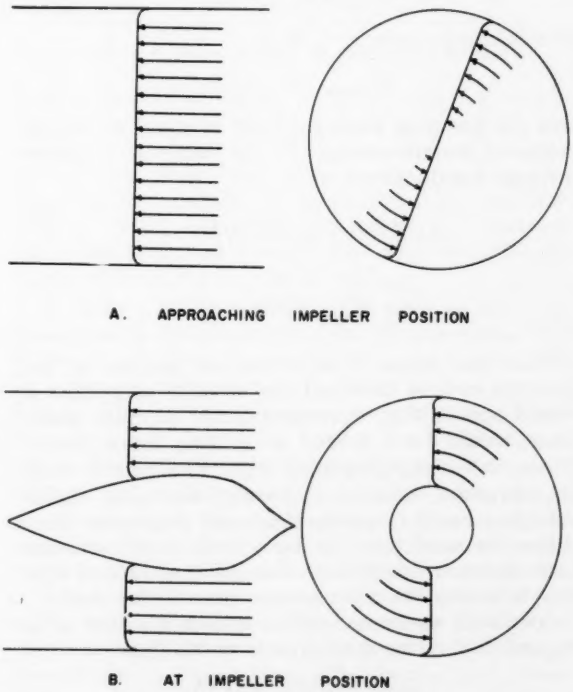


Figure 4. Velocity Profiles in Jet Duct

Because of the uniformity of flow, constant lift across the impeller blade can be achieved with a constant hydrofoil section which decreases in length with increasing radius, modified only at root and tip as described above.

The blades should be as thin as is consistent with strength requirements, which also dictate that the thickness of the blade must taper from a maximum at the root to a minimum at the tip. Since the lift is to be uniform, this thickness variation can be a straight line function of the radius.

To actually accomplish the design of the impeller, an analysis of the required flow rates and quantities must be made. These conditions can be determined partly by calculation and partly by experiment.

The quantity rate of flow through the jet duct system must be constant and is equal to the product of the velocity at any point and the cross section area of the duct at that point or:

$$Q = A_x V_x = \text{constant}$$

The thrust produced by the jet will be:

$$T = \rho Q(\delta V)$$

Where

ρ = mass density of water
δV = increase in velocity through the jet duct.

The inlet velocity is equal to the difference between the velocity of the craft and the wake velocity. The difference is the speed of advance or:

$$V_{inlet} = V - V_W = V_A$$

The discharge velocity is then:

$$V_{discharge} = V_A + \delta V$$

and the pumping head required is equal to the increase in kinetic energy of the water as it passes through the ductwork or:

$$H = \frac{1}{2g}[(V_A + \delta V)^2 - V_A^2]$$

$$= \frac{\delta V}{2g}[2V_A + \delta V]$$

Since the thrust is equal to the product of the quantity rate of flow and the velocity increment it would appear that increasing either of these quantities would be a means of gaining more thrust. However the pumping head required is greater with an increased velocity increment and also higher velocities result in greater frictional resistance. Thus it can be seen that the best method of obtaining high thrust is to increase the quantity rate of flow by increasing the cross section area of the duct.

Assuming the cross section area of the inlet to be A_i and that of the discharge to be A_d then:

$$Q = V_A A_i = (V_A + \delta V) A_d$$

or:

$$\delta V = V_A\left(\frac{A_i}{A_d} - 1\right)$$

and

$$T = \rho A_i V_A(\delta V) = \rho A_i V_A^2\left(\frac{A_i}{A_d} - 1\right)$$

$$H = \frac{V_A^2}{2g}\left[\left(\frac{A_i}{A_d}\right)^2 - 1\right]$$

Before design of the impeller can be started, it is necessary to know two basic factors regarding the hull of the craft. These are the resistance at the design speed, and the speed of advance at the inlet duct opening, i.e., T and V. Once these have been determined, and the duct cross section area established, the pump characteristics can be computed.

The thrust and speed of advance will be obtained from the experimental program which will be outlined later. The cross section area of the duct will be a function of the allowable space in the craft as determined by the hull design and duct design phases of the program. Once the impeller design has been completed it will be necessary that it too be subjected to test for evaluation and refinement.

The practical design of the impeller assembly also requires detailed consideration. This assembly consists of the impeller and the hub, the drive shaft fairing, and the suction and discharge contra-vanes.

One of the disadvantages of the hydraulic jet is the lack of accessibility for maintenance of the impeller. With proper design it appears that the impeller assembly can be made removable so that this difficulty will be obviated.

Figure 5 illustrates how this can be accomplished. The section of the duct in way of this assembly can

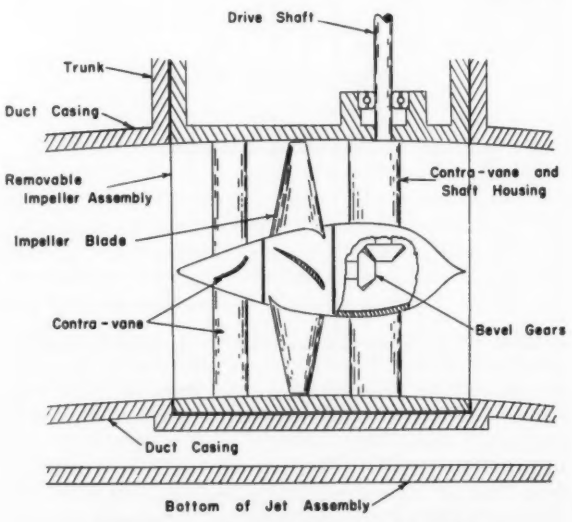


Figure 5. Removable Impeller Assembly

be separate from the main duct so that it can be lifted out for repairs. It is, of course, essential that

the top of the trunk housing this assembly be above the waterline of the craft.

The fairing of the gear housing and impeller hub is also important. The recommended shape of these components is similar to the general shape of the duct itself, i.e., a half-cycle of a sinusoid of revolution forward of the impeller centerline and a quarter-cycle of a sinusoid of revolution aft of the impeller centerline as is shown in Figure 5. The actual dimensions of these components must be determined by the detail design considerations but the diameter should be the maximum obtainable.

The contra-vane design must be considered along with the impeller design itself. The angular variation from the centerline to the wall of the duct will be directly related to the pitch of the impeller blades. Several treatises on axial flow pump design are available which describe in detail the derivation of the optimum combination of vanes and impellers.

Machinery Design

The main propulsion machinery of an hydraulic jet propelled craft of this type will differ from that employed with other forms of propulsion systems. Both the available buoyancy distribution in the hull and the requirement for rotation of the jet assemblies must be taken into consideration.

Because of the fact that the stern is sloped at a flat angle the buoyancy in this area will be insufficient to support the main propulsion engine without excessive trim when the craft is in a light condition. Thus the location of this engine further forward is dictated. The coupling of the power to the jet assemblies which must rotate through 360° is also a problem. From a practical standpoint it is also desirable that the rotation of the jet assemblies, which will require a fair amount of power, be accomplished by the same prime mover.

It is possible to couple the prime mover to the impellers and rotating devices mechanically, hydraulically, or electrically. However, from the standpoints of ease in operation and maintenance as well as simplicity of design it appears that electrical coupling is the most practical.

The prime mover, then, would be either a diesel or a gas turbine driving a generator. Although an alternating current system is attractive because of its lightness, it would require more complex control systems and would be more difficult to maintain. Therefore a direct current system is recommended. Four DC motors would be required: one for each jet impeller and one for rotating each of the jet assemblies.

With the flexibility which jet propulsion offers, there are several combinations of operation of these four motors which could be employed in maneuvering. Each of the jet impeller motors could be made reversible and separately controlled. The jet assembly rotating motors could likewise be individually controlled giving the helmsman a wide variety of combinations which could be used.

As a part of the design requirements, however, it has been established that the control system should be simple enough to be operated by relatively untrained personnel. Therefore, it is felt that maneuvering control should be limited to rotation of the jets and divorced almost completely from the velocity flow through the impellers.

Hence, the propulsion motors should operate in one direction only, and their control should be limited to three ahead speeds, namely idling, cruising and maximum. The control system for the rotation of the jet assemblies will be covered in a separate section. A diagram of the machinery system is shown in Figure 6.

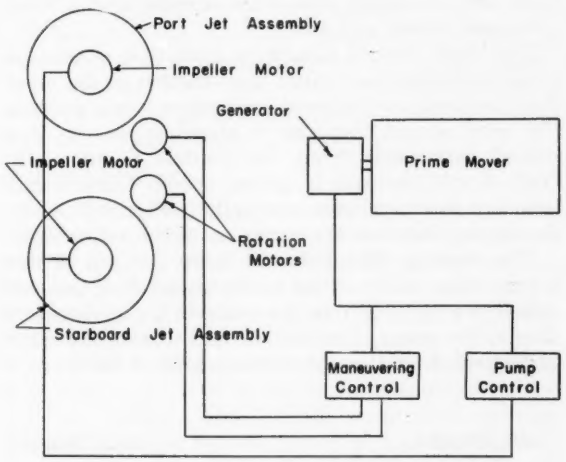


Figure 6. Diagrammatic of Machinery System

As indicated in Figure 6, the jet rotating motors should be mounted on the hull proper and the impeller drive motors should be mounted atop the rotating assemblies. These latter motors can either be mounted horizontally or vertically. Although 360° rotation of the assemblies is required, the electrical leads need not pass through slip rings since the rotation will also be limited to 360°.

A fundamental consideration in the machinery design phase is the mounting of the jet assemblies. The bearings on which these assemblies are carried will be subjected to horizontal forces as well as vertical forces. The entire thrust is transmitted through them and yet they must permit the assemblies to rotate freely under all conditions of operation.

To eliminate the sealing problem, which is almost unsolvable with the large diameters involved, assemblies should be carried in free flooding trunks extending above the waterline. The lower bearings will therefore be exposed to corrosive action of sea water and to particles of foreign matter. The use of teflon rollers in this area is suggested. The design should also include access plates in the deck above so that the entire assemblies can be removed for servicing.

Control System Design

The fundamental principle underlying the design of the hydraulic jet control system is simplicity. The control should be designed so that the natural reactions of the operator will result in desired motions of the craft. Yet, the great advantage of the hydraulic jet lies in its ability to propel a craft through a wide range of maneuvers, some of which require complex jet positioning. It therefore is a design requirement that the control system perform normal maneuvering functions without undue complexity and yet be sufficiently flexible to take maximum advantage of the characteristics of the propulsion device.

The most simple forms of control for a marine vehicle are a steering wheel for turning and a lever for speed, ahead and astern.

The lever control should be such that when it is in a neutral position there is no motion of the craft. As it is advanced forward from the neutral position the craft should increase in ahead speed. As it is pulled backwards from the neutral position, the craft should increase in astern speed. These conditions are shown diagrammatically in Figure 7, where the arrows indicate the direction of the jet stream.

The steering wheel should drive the jets so that a right turn of the wheel in the ahead direction will result in a right turn of the craft. It is also desirable that in the astern direction, a right turn of the steering wheel should result in a swinging of the stern to starboard in the same manner as an automobile. The steering wheel and jet positions to accomplish these motions are shown in Figure 8.

To accomplish some of the more sophisticated maneuvers of which the jet is capable, a combination of these controls can be used. For example, Figure 9 illustrates the position of controls and jets which would result in a sidewise crabbing motion to port or starboard.

This type of control system can be designed for mechanical, hydraulic, or electric operations, but since electric power is to be available and since the jets will be rotated by electric motors it is obvious that electric controls would be the most practical.

The simple servo system shown in Figure 10 demonstrates the manner in which the desired motions can be obtained. A slave synchro is geared to each jet rotation motor with a feedback system such that the jet will be positioned at the angle demanded by the synchro. The port and starboard slave synchros are driven in the same direction by a master synchro at the control station. They are made to operate in opposite directions by a differential synchro which is wired between them and which is also located at the control station.

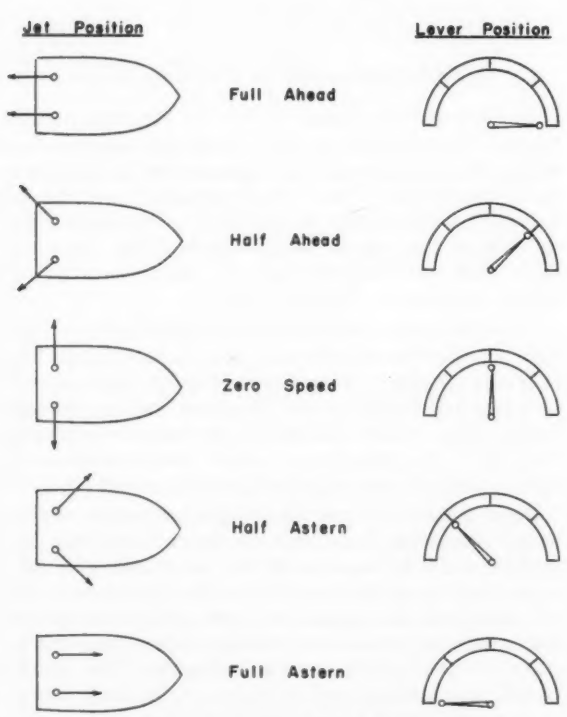


Figure 7. Lever Control Action

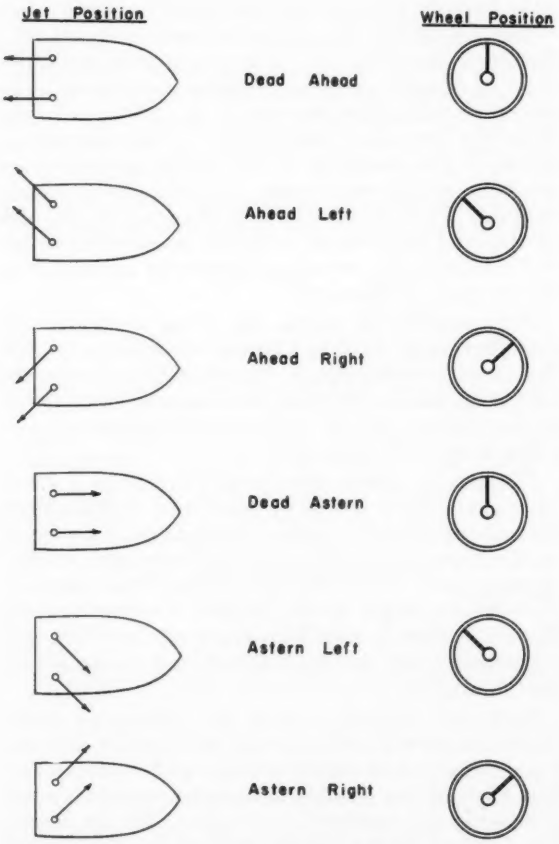


Figure 8. Wheel Control Action

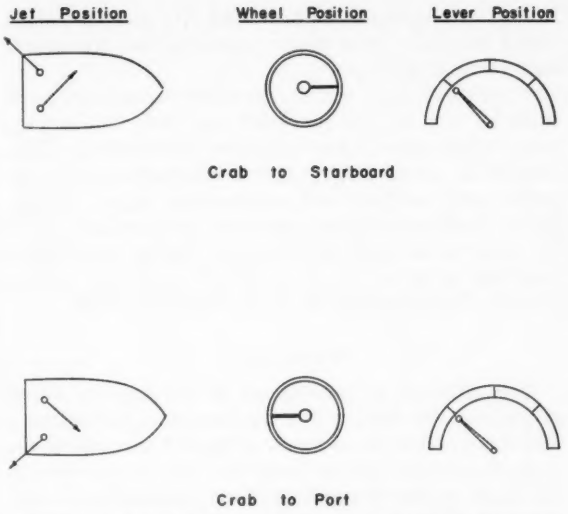


Figure 9. Control and Jet Positions for Special Maneuvers

The master synchro is operated by the steering wheel. If the jets are positioned for ahead operation, turning of the wheel will cause them to rotate in the same direction thus giving a steering effect.

The differential synchro enforces an angular change between the slave synchros which angle is equal to the angle of the differential with the neutral position. The shaft of the differential synchro can be connected through suitable gearing to the ahead-astern-speed control lever. When this lever is in the neutral position, the jets will be 180° apart. As the lever is moved forward the angle between the jets decreases and they assume a position of forward thrust. As the lever is moved back the angle between the jets increases and they assume a position of astern thrust.

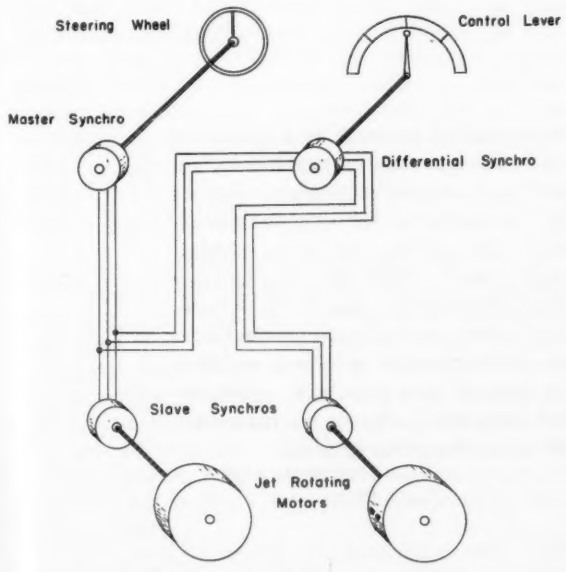


Figure 10. Control Servo System

Both the master synchro and the differential synchro should be limited to 180° of travel. This will prevent rotation of the jets beyond the allowed 360° and will also prevent uncontrolled jet motion. It is probable that the synchros themselves should be geared down, particularly the differential, to prevent over-riding and hunting.

This control system should provide maximum flexibility and simplicity to take full advantage of the maneuvering qualities of the hydraulic jet.

EXPERIMENTAL PROGRAM

Supplementing the design program, a number of experiments are required to resolve design parameters and to achieve optimum flow conditions. These experiments involve the hull design, the duct design, and the impeller design.

Hull Model Tests

In order to design an optimum propulsion system the resistance characteristics and the flow conditions around the hull must be known. When the hull design has been completed a large scale model should be constructed and a complete series of resistance tests conducted.

In addition to the resistance tests, a wake survey is needed in the area in which the propulsion device will be located. This should consist of velocity measurements at several points across the hull extending from the hull surface to the extremities of the boundary-layer. Velocity profiles should be prepared to guide the designer in locating the jet intakes and discharges to obtain maximum use of the flow variations.

Duct Model Tests

The actual configuration of the intake and exhaust ducts has already been established. Although it might be desirable to conduct a series of tests on different designs to evolve an optimum, this procedure would be inordinately expensive and time consuming.

The dimensions of impeller diameter, impeller centerline height, and jet assembly radius (d, h, and R of Figure 2) will have been determined on the basis of other design compromises. Once these have been established a scale model representing the jet ductwork can be constructed.

This model could be mounted in an existing rectangular circulating water tunnel in which the velocity distributions found on the hull model could be simulated. The purpose of these duct model tests would be to obtain complete velocity distributions throughout the duct and to determine the optimum angles of the intake and discharge contra-vanes. The same model could then be used as an impeller test facility.

In order to make this evaluation the model would have to be flexibly supported on the tunnel wall so that both vertical and longitudinal forces on the whole assembly could be measured. This can be accomplished by hanging the assembly from a rack of transverse and vertical flexures. Since the tunnel would operate at low pressures, watertightness could be maintained by thin rubber septa whose effect on the measured forces could be accounted for in the calibration of the instrument system.

With the tunnel operating at different water velocities, measurements could be made through pressure taps at numerous points along the duct wall. In addition, velocity profiles in the impeller position could be obtained by pitot tube and the flow resistance of the complete assembly measured.

These measurements would be made first with the ducts free of all vanes. Then the inlet grill would be installed with adjustable vanes whose angles could be varied to determine optimum flow conditions. Similarily, any discharge vanes required would be fitted and their angle optimized. The inlet and discharge vanes would then be locked in the position giving the most satisfactory flow conditions and the velocity distributions in way of the impeller could be supplied to the designer to be used in completing the impeller design.

Impeller Tests

The impeller assembly should be fitted into the duct assembly model for test. This model impeller assembly should have adjustable impeller blades and adjustable inlet and discharge contra-vanes. The drive motor should be installed atop the assembly with provision for measuring horsepower and revolutions per minute. Thrust and lift measurements could be made from strain gages on the transverse and vertical flexures.

A series of open water characteristic curves could then be run on the powered assembly by varying both water speed and impeller revolutions. Tests should be made with various combinations of impeller pitch setting and contra-vane angle settings. From these results the optimum combination could be determined and the impeller design established together with information which could be used to predict the performance of the full scale craft.

CONCLUSIONS

It is difficult to foresee all of the factors which enter into the design of a marine craft, particularly one equipped with an unusual type of propulsive device. In the foregoing program, the major factors involved in the design have been outlined and more detailed guide lines have been drawn where available information permits.

When the program is carried out it will undoubtedly be necessary to vary somewhat from the outline established and perhaps to modify extensively some of the design concepts which have been described. It is believed, however, that if this program is followed and a vessel constructed, it will demonstrate the many useful characteristics of the hydraulic jet as applied to special purpose marine craft.

ACKNOWLEDGMENTS

The program described in this article was developed for the U. S. Army Transportation Corps under Contract DA-44-177-TC-409.

Magnesium has been the subject of a revival of interest as a practical engineering material. Besides its weight advantage, ease of machining is a characteristic which may offset its present cost margin over aluminum, its largest competitor. Volkswagen is using the material for engine blocks. Westinghouse uses magnesium extensively in die castings for small motors. Magnesium-thorium alloy sheets have been used in ballistic missile construction. The high performance Canadian interceptor, the Avro Arrow, has extensive use of magnesium alloy sheet, plate, extrusions and castings, both in air-frame and engine construction. Techniques for grinding, welding and machining magnesium have been developed to a practical, commercially feasible degree. It is expected that increased interest by manufacturers, particularly automobile makers will cause the price to drop.

—from THE IRON AGE
July, 1959

"THE MARINE ENGINEER & NAVAL ARCHITECT"

MACHINES FOR PRECISION REDUCTION GEARS

ACKNOWLEDGEMENT

This article appeared in the April, May and June 1959 issues of "The Marine Engineer and Naval Architect." The author is Mr. A. Sykes, Technical Director, David Brown & Sons (Huddersfield) Ltd.

THE need for gearing as a means of rendering the high speed of steam turbines compatible with the desirable low propeller speed was appreciated by Sir Charles Parsons as far back as 1897. The earliest large-scale applications of the steam turbine for marine propulsion used direct-coupled propellers, an arrangement which did not allow either propeller or turbine to operate under the best conditions. In practice, the propeller was run too fast for maximum efficiency and, correspondingly, the turbine was run too slowly, which meant that it had to have a very large rotor in proportion to its output. This made it costly as well as inefficient.

NEED FOR ACCURACY

Helical gears cut during the early part of the present century produced results which were reasonably good from the power transmission point of view but, where they were run at high speeds, they were usually rather noisy as no very precise gear-cutting machines were available and the contact area obtained between the meshing teeth was not all that could be desired. For this reason the gears generally had to be made larger than would otherwise have been necessary.

While it was found that the hobbing process generally gave the best type of gear, since the process is a continuous one in which cuts of the same magnitude are taken successively on every tooth of the gear, the general inaccuracy of master wheels of hobbing machines was such that there were appreciable errors of motion between the driving worm and the master wheel on the table. This led to noise frequencies corresponding to the spacing of the teeth in the master wheel.

ORIGIN AND PURPOSE OF CREEP MACHINES

Errors arising from a master wheel attached directly to the work table or work spindle produce a series of errors lying on lines parallel to the axis of the work, and Sir Charles Parsons conceived the idea that if high spots produced on the tooth in this manner could be distributed so that they did not all make contact at the same instant, the noise level would be more favorable.

He first of all introduced a form of differential gear which displaced the table by a certain amount during each successive revolution with respect to the driving worm, the amount of the displacement corresponding to either a fraction of a revolution of the worm or some whole number plus a fraction. Early efforts in this direction, on account of the additional mechanism involved, gave a rough finish on the teeth and often resulted in their being cut con-

siderably thinner than the width of the corresponding tooth space on the hob, due to the irregular displacement of the table during each successive revolution.

Sir Charles Parsons co-operated with the firm of William Muir, of Manchester, who had experience in the manufacture of gear-cutting machinery. They were well known for their rack-type gear-generating machine, which was a development of their puncher-slotter, and they were also one of the early makers of wormwheel-generating machines.

The wormwheel was generally attached rigidly to the table but eventually a type of machine was evolved in which the worm and wheel drive to the table was mounted separately not quite concentric with the work spindle. The table was thence driven by a spur wheel and internal gear, which gave a simpler mechanism than some of the early patents and had the desired effect of distributing the errors arising from the worm and wheel in a favorable manner. Unfortunately, it did not give any displacement of the work relative to the final driving gear attached to the table.

This arrangement produced gears which were still somewhat rough in finish, although better than previous efforts, and it did avoid the undesirable high-pitched notes experienced with the direct worm-and-wheel drive to the table.

EXPERIENCE AND DEVELOPMENT

The firm of William Muir, afterwards Muir Machine Tools Ltd., and later David Brown Machine Tools Ltd., made most of the early machines used for producing marine gears and they have continued to make a sustained effort to improve the accuracy of gear-hobbing machines. The first and most important step was that of producing good master worm wheels to give nearly constant relative motion between the driving worm and the work-piece and more accurate motion between the hob used for cutting the teeth and the work on which it was operating. The company's experience in this direction is quite unique in that there has been not only a continuity of development but also a continuity of orders for machines which enabled them to take advantage of experience gained and to keep in regular contact with users of their machines in various parts of the world.

More recently, since they became part of the large gear-making organization of David Brown Industries Ltd., employing gear-cutting machines of many different makes and different types, they have had the great opportunity of following the effects of their development. The results of this are that they have been able to build up not only a technically-trained design and management staff, but also a technically-trained production staff. This is important in the manufacture of precision gear-cutting machines, as the effect of trained and experienced men at every stage has a pronounced effect on the ultimate result.

They still make a special point of considering the views expressed by their many customers and weighing the merits of different proposals and the results of experimental work, so that their current products can truthfully be said to combine the best opinions of users in all countries.

The Admiralty, the National Physical Laboratory, Lloyd's Register of Shipping and the Mechanical Engineering Research Laboratory have all given David Brown Machine Tools Ltd. considerable support in their efforts to improve the product.

The Admiralty has been particularly interested in securing high-accuracy gears, the size and weight of which would be the smallest practicable and which would not produce undesirable noise. Quite apart from the discomfort to engine room staff, noise has a serious naval disadvantage in that geared ships can be detected at a distance by an enemy equipped with suitable listening apparatus. Accuracy is also of great interest to Lloyd's Register as a factor in the Rules for the Construction of Machinery and as a measure of the insurance risks involved.

The improvement in accuracy has been accompanied by parallel attention to methods of inspection and to design for greater rigidity. The resultant better alignment of the machines has an important effect on the quality of work they perform. Skill and care in assembly and erection are vital, for the most rigid type of construction can still allow slight movements of massive beds and columns even when foundations are as nearly ideal as possible.

ELEMENTS OF THE HOBBING MACHINE

The two principal requirements in a good hobbing machine are accurate master wheels and accurate lead screws, which govern the rate of movement of the hob saddle. Special machines have been developed for producing these components to the standard of accuracy required and it is safe to say that the production of master screws no longer represents any serious problem.

Although it is now quite practicable to obtain a high degree of accuracy over the full length of even the longest lead screw required, it is well to bear in mind that in a hobbing machine it is seldom necessary to operate on a gear of which the face width of one helix is greater than 36 in. It is, therefore, necessary to exercise the closest scrutiny of errors within any length of 36 in. at any part of the screw, this being of relatively greater importance than the position of any two points separated by a long distance.

Master wheels are made to the limits laid down by British Standard No. 1498 : 1954. It is sometimes thought that it is relatively easy to meet this specification but this is by no means the case even though, for example, it may allow a tolerance for cumulative error in master wheels which is easily possible of achievement. This Standard has been drawn up so

as to give the widest tolerance where circumstances will allow, and in a master wheel it is not the total cumulative error that is the most difficult to achieve but that over relatively short lengths of arc.

David Brown machines are constructed with a view not only to securing original accuracy but maintaining it for a reasonably long working period. For example, the master wheels are made in a high-tin bronze and the master worm of case-hardened steel accurately ground on the profile, a combination which has been found to give the longest life to the master gear. Overstress can arise when starting a machine from rest after it has been standing for a long period and arrangements are made to relieve the load on the table and introduce lubricant between the bearing surfaces before starting the machine.

Various methods have been used for relieving the weight on machine tables which can, in some cases, be very large, rising to as much as 70 or 80 tons in a single gear. One method has been to employ a multiple-lever arrangement operating on a thrust bearing directly underneath the work spindle. The compensating load is easily adjusted by varying the amount and position of the applied weight in similar fashion to that of an ordinary platform weighing machine.

Another method has been to employ an oil pressure cylinder directly underneath the main spindle; both these methods unfortunately have the effect of applying the balancing load relatively near the center of the table without very much relief at more remote parts, thereby causing it to bend in mushroom form, and the latest and most satisfactory arrangement is to use oil pressure operating on a cavity of large area extending as near as possible to the outer edge of the table, thereby reducing the bending effect to a very considerable degree.

GENERAL DESIGN FEATURES

There are two other points which can assist in attaining precision, first, in arranging the gears between the master worm shaft and the hob spindle so that they run at the most convenient speed and include gears which can be made in the most precise manner. In this connection it is always desirable to avoid high-ratio worm wheels running with multiple-thread worms, as such wheels are not only difficult to produce to precise limits, but their accuracy is affected in a pronounced manner by the way in which they are adjusted and in subsequent wear or movement of the thrust bearings.

A second point which has arisen from long experience is that, although present-day worm wheels are highly efficient, this is a comparative term and the heat produced by frictional losses is greater than in the case of spur and helical gears. It has been shown beyond all doubt that the temperature rise produced by gear drives at various parts of a machine can have an important effect on the maintenance of alignment.

Wherever possible, intermediate gears are made in such a way that they can be either accurately hobbed and shaved or finished by grinding and particular care is also taken in the manufacture and location of change wheels. The securing of change wheels has been given careful thought and the present method is to locate these by spring clips, as shown in Figure 1, which not only assists in rapid operation and setting-up, but also avoids any straining of the change wheel pins which sometimes occurs when tightening-up nuts.

The minimum diameter of lead screws is laid down in B.S.1498 and represents a marked advance on previous practice, as the use of large-diameter screws assists in attaining original accuracy and long life and ensures freedom from the distortion which can result from stresses in service.

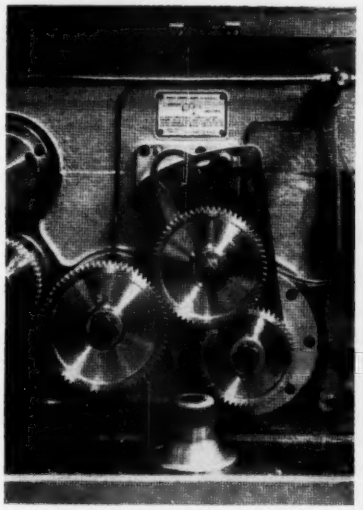


Figure 1. Method of securing change wheel by spring clip.

TEMPERATURE EFFECTS

Some reference has already been made to temperature effects and there is no doubt that the temperature rise at local points can be many times the variation in atmospheric temperature during the period of cutting a gear.

Recent designs ensure as far as possible that fast-running components are housed in gearboxes in such a position that heat conductivity from them does not affect alignment of important slides. Figure 2 shows a machine in which the main gearbox is entirely separate from the base of the machine.

The drive to the hob in any machine must be such that the hob can be adjusted to or from the work spindle to allow for different diameters of work while the hob spindle must also be capable of travelling across the face of a gear. This normally means relatively long splined shafts in two directions connected by bevel gears or other suitable means. In addition there must be a mechanism, generally involving a lead screw, to maintain an ac-

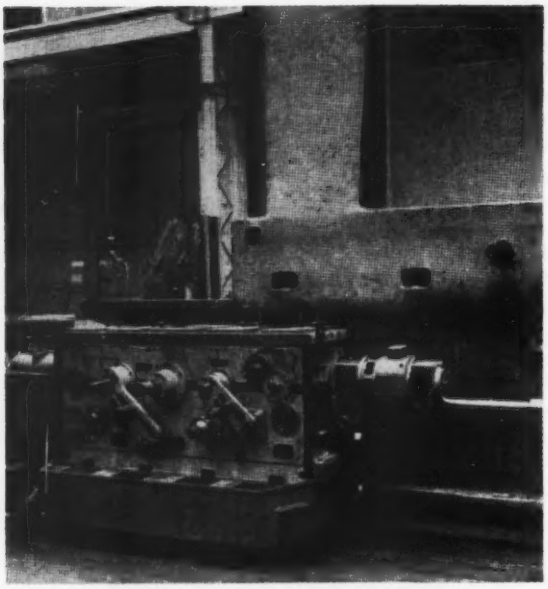


Figure 2. Gearbox isolated from base of machine.

curate relationship between the advance or retardation of the work and the hob travel to give the desired helix angle.

Recent efforts have been directed towards carrying the driving mechanism on an entirely separate slide from that carrying the feed screw mechanism, the intention being that the higher temperature of the driving gears will not influence the main slide which guides the hob saddle, and so that it is kept in the desired relationship to the axis of the work. Figure 3 illustrates a recent patent covering this arrangement.

LOCATION OF WORK SPINDLE, HOB SPINDLE AND MASTER WORM

It is important to maintain the axis of the work spindle in a constant position under all conditions and this also applies to the position of the master worm both diametrically and in the direction of its axis. Two useful steps have recently been taken in this direction: one is to use pre-loaded roller bearings or pre-loaded ball bearings to locate the main work spindle and table which can thus be rotated at the required speeds with virtually no free lateral or axial movement. Another method has been to locate important bearings by an oil pressure film fed into the bearings at suitable points which will maintain the position of the axis in a constant position irrespective of minute irregularities which may exist on the shafts and spindles even after grinding on the most precise machines known.

Figure 4 illustrates the use of pre-loaded roller bearings for location, and Figure 5 shows the oil pressure method for maintaining a constant position of the work spindle.

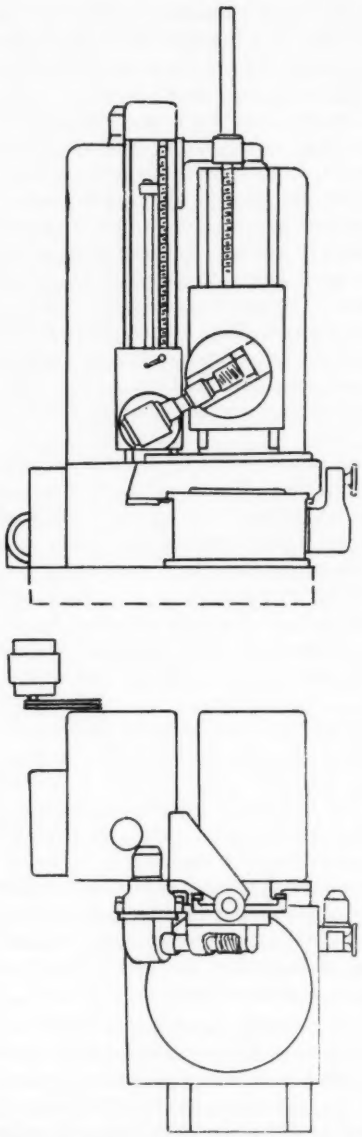


Figure 3. Patented arrangement with separate head carrying feed screw mechanism.

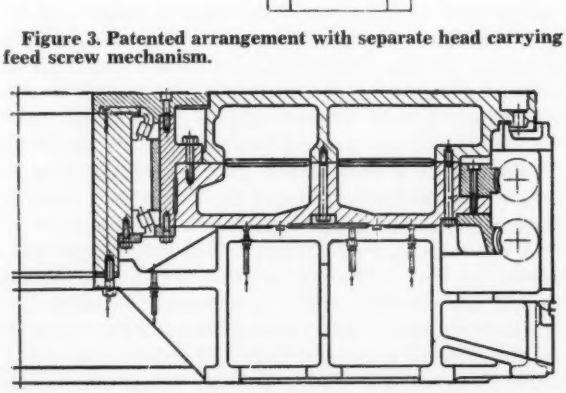


Figure 4. Pre-loaded roller bearings for work spindle and table.

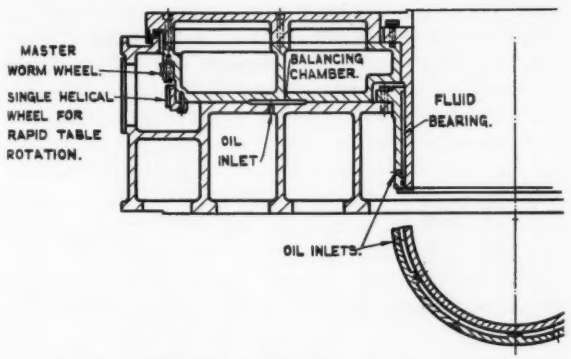


Figure 5. Work spindle located by oil pressure film.

PRODUCTION SPEED

Speed of production depends on the ability to run a machine at high speed without vibration and without temperature rise at vital points. In the process of cutting precision turbine gears, the hob itself presents no particular problem when cutting normal materials, although it might present some difficulties in hobbing large gears of high-tensile steel. This would mean that in a finishing cut the hob would have to maintain its size very closely after carrying out a considerable amount of work. Here again, rigidity has an important effect on the life of a hob. Some assistance can also be secured in this direction by the use of climb-cutting and a point is made of adjusting all David Brown machines in such a way that they can be used for climb-cutting, that is, a direction of feed which is opposite to the direction of the movement of the tip of the hob in its cutting zone.

MOUNTING WORK PIECES

Machines are so designed that in setting-up, a wheel mounted on its shaft can be handled up to the largest sizes and the setting carried out with reference to the journal bearings. This eliminates any errors which might arise in setting from the wheel rim, which is more difficult to machine with close accuracy than a shaft which can generally be finished to precise limits before assembly. It is well to bear in mind, however, that no setting can be more accurate than the original finish and accuracy of the shaft itself.

There are differences of opinion as to whether the work axis should be in a vertical or horizontal position and machines of both types are in existence for both wheels and pinions. There are three aspects which affect this problem:—

(1) Floor space occupied
(2) Convenience of setting-up
(3) Convenience of operation.

In general, machines for either wheels or pinions with the work axis vertical occupy the least floor space, although they may have a greater overall height. With regard to convenience of setting, there is not a great deal to choose, except that work with the axis in a vertical position does not undergo any bending during setting, as the gravitational effects at all points are symmetrical with regard to the axis. It is sometimes claimed that the operator can judge the relationship of hob and work more easily when setting, particularly for a second or subsequent cut, although it can be stated after considering the views of many operators, including those within the company's own works, that there is little to be said either way and it is just a matter of getting accustomed to one method or the other.

On all important machines the lubricating system is duplicated and is so interconnected with the main driving motors that a machine cannot be started until the oiling system has attained its normal pressure.

David Brown gear-cutting machines can be so constructed that, if required, they can be used for either hobbing or shaving and, when convenient, the two operations can be carried out in sequence on any given work piece without removing it from the machine. Independent drives to the table are provided so that it can be run at suitable speeds for both hobbing and shaving. The higher speed generally used for the latter is also a convenience for the setting-up of the work piece and can be a useful time-saver.

PINION MACHINES

The point often arises whether pinions should be cut on the same machine as is used for wheels or whether a separate machine should be provided. Wherever the quantity of work to be done justifies separate machines for the two duties they should be provided, for pinions having small numbers of teeth must rotate more rapidly for a given hob speed than wheels having a large number of teeth. This not only has an effect on the general design of the work spindle and table bearings, but it also has a marked effect on the running speed of the change wheels.

In some cases, where it is essential that the same machine should be used for cutting both wheels and pinions, a separate low-ratio drive is operated through a dog clutch which transfers the drive from the motor to the work spindle at a point between the change wheels and the master gear. This avoids running the latter at an excessive speed and also avoids undue strain on the change wheels. It should, however, be recognized that, in general, where a machine must cut both wheels and pinions it will usually have to operate at a somewhat slower cutting speed in the case of pinions than would otherwise be the case.

Table bearings and work spindle bearings are de-

signed to be capable of running at speeds suitable for shaving. This also makes the table capable of running at speeds suitable for use with multiple-start hobs which can, with advantage, be employed for roughing and also for finishing if the cutting operation is to be followed by shaving.

Difficulty in finishing gears with multiple-start hobs arises not in the machine itself but in making and maintaining the required degree of accuracy in the hob and also in that it has fewer cutting edges in the working zone of one thread.

MOUNTING OF HOBS

David Brown Patent No. 706,055 is of particular importance in this connection. This concerns hobs which are mounted permanently on their own spindles, as shown in Figure 6, and has two important effects. Firstly, it enables bearings to be provided very close to the cutting zone of the hob and, secondly, the hob can be resharpened without affecting its ultimate accuracy and without introducing any setting difficulties such as arise when it is mounted on a spindle and has to be removed for sharpening. It has been found possible not only to attain a much better finish but greater precision in the tooth profile. The use of multiple-start hobs also becomes more practicable by this method.

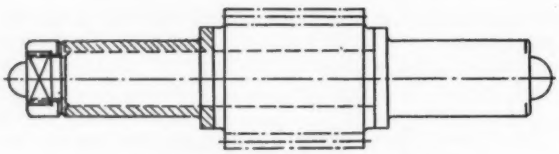


Figure 6. Hob permanently on spindle.

KINEMATIC DESIGN

The arrangement of gearing for a typical hobbing machine is shown in Figure 7. A differential gear is normally included as this makes the change wheel calculation more convenient and also facilitates changing the rate of feed when desired during cutting operations, although it should be emphasized that it is desirable not to interrupt a finishing cut for this purpose if it can be avoided. Machines can be provided for cutting wheels having prime numbers of teeth, although this can also be achieved by the fractional indexing method if the need arises. It is a matter for discussion outside the scope of this article as to whether prime numbers are ever necessary in large wheels.

INSPECTION

The inspection of hobbing machines is a subject to which a great deal of study has been devoted and there has been steady evolution of instruments designed to yield reliable measurements in the most

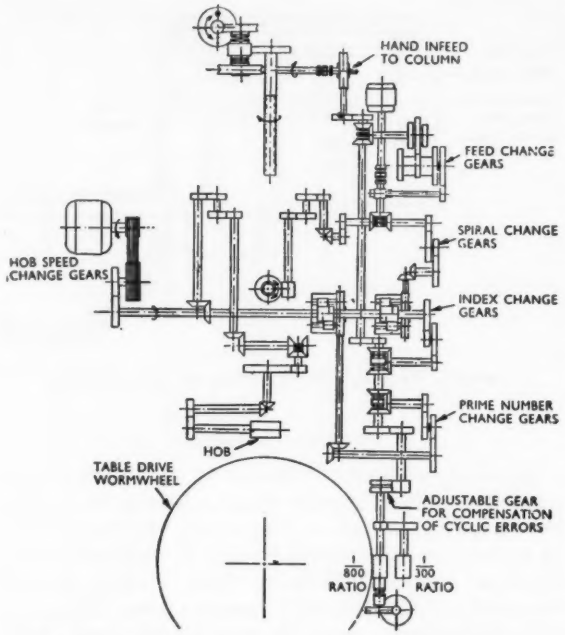


Figure 7. Kinematics of typical hobbing machine.

convenient manner. The human element has been eradicated as far as possible. For example, in the retractable pitchometer, described below, positioning depends entirely on spring pressure acting against dead stops, an indicator is used for zero-positioning of the work with reference to the measuring head and the effect of manual pressure on the accuracy of readings is entirely eliminated; crossed strips have replaced pivots where practicable.

CHECKING FEED SCREWS AND MASTER WORMS

A graduated 40-in. (1 meter) scale is used as the reference standard and its accuracy is verified by the National Physical Laboratory to be within 0.0001 in. (0.0025 mm.) at 68° F. The interval between graduations on the scale is 0.05 in. (1.27 mm.). When it is being used this scale is placed parallel to the screw under test, which is normally supported on V-blocks, and a microscope carried on a movable head, is focused on it. The measuring head is moved along a slide parallel to the axis of the screw and finally set by fine-pitch adjusting screws. The head carries a sensitive indicator operated by a lever having a stylus point which is brought into contact with the first thread flank to be measured. Both the microscope and the indicator are set to zero. The thread is then withdrawn bringing the stylus out of contact with the thread, and moved until the stylus can be brought into contact with the next thread to be measured. It is adjusted so that the indicator again reads zero, after which the distance moved along the scale and any error in the screw can be read through the eyepiece of the microscope which

incorporates a short scale graduated by 0.0001 in. (0.0025 mm.). This process is repeated over successive threads. The apparatus can be readily and accurately adapted for metric screws, by converting the metric dimensions to inch dimensions and by the use of the graduated scale in the eyepiece of the microscope.

When dealing with screws longer than 40 in. the head is left in position after the last reading has been taken and the scale is moved along until its zero mark comes under the hair line in the eyepiece of the microscope. Cyclic errors over a selected convolution of the thread are detected by taking longitudinal readings of the measuring head at, say, ten equally-spaced intervals of one or more convolutions of the thread, a graduated circle being mounted on the screw being tested. A similar procedure is followed for checking the pitch of master worms.

CHECKING MASTER WHEEL PITCH ERROR

This is carried out by means of the retractable pitchometer, mentioned above. This instrument is used for the pitch measurement of spur, helical and worm wheels over any desired length of arc, while minimizing the effect of the human element when taking the readings.

It consists of two main parts, a top plate carrying the gauging head and a bottom plate to which it is attached by means of flat flexible springs. These springs allow the top plate to be moved relative to the bottom plate in a direction approximately corresponding to a radial line passing through the center of the gear, without permitting any cross movement. They also enable the gauging points to be withdrawn from contact with the gear being measured and returned to their exact working positions. The gauging head has a bell-crank lever with a ball-ended stylus to make contact with the tooth, at one end. The other end of the lever makes contact with the stem of a dial indicator. Two tension springs keep the spring plates against the surface of a cam, which can be rotated by a ball-ended lever to move the top plate radially. The gauging position is determined by hardened stops. These instruments are used in pairs, one for zero setting and the other to indicate differences in pitch over the number of teeth or length of arc selected. Figure 8 shows such a test being carried out on a large-diameter fine-pitch worm wheel. It is important that the instruments should be set at the same height and in such a position that they will make contact at identical points on succeeding teeth. The need for this is emphasized in British Standard No. 1807, Clause 10 (a).

The first reading having been obtained, the ball-ended lever is moved through an arc of about 90 degrees to the position shown so as to withdraw the stylus clear of the tooth and allow the gear to

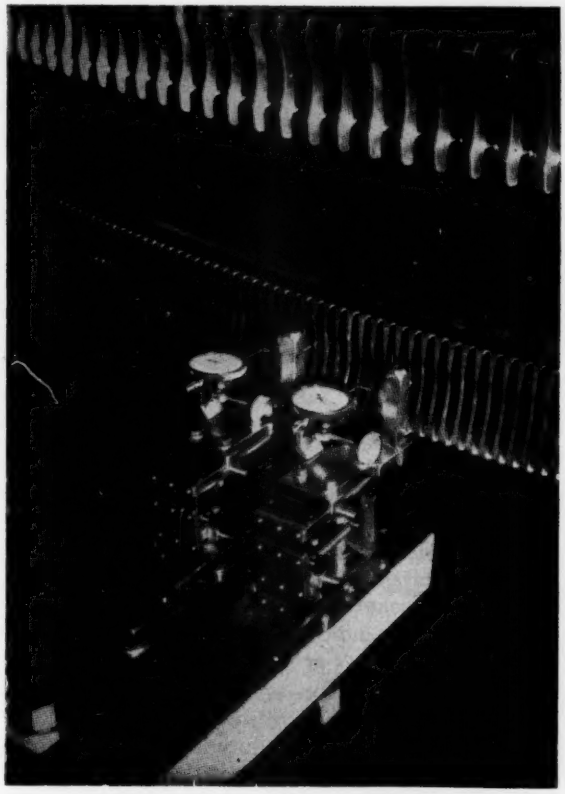


Figure 8. Retractable pitchometer.

be rotated through any desired arc for making a second reading. Careful rotation of the gear and adjustment by hand, if necessary, enables a zero reading to be obtained on the zero setting dial gauge. The variation in overall pitch covering the span of teeth selected from that of similar spans taken from any other datum points is shown on the second dial gauge. The average of all the readings taken is calculated and the error over any selected arc is the difference between the reading for that arc and the average reading.

A convenient way of using this instrument for checking maximum cumulative pitch errors is to plot a curve of adjacent pitch errors, or of pitch errors over short spans of teeth, and determine from this over what length of arc the maximum cumulative error occurs. The two instruments referred to are then set at positions corresponding to this length of arc; a series of tests taken from different datum points will then verify or otherwise the error shown in the diagram and will eliminate the summation of small errors arising from carrying out a large number of tests over either adjacent pitches or short lengths of arc. These instruments are made so that they can, if desired, be brought sufficiently close together to check adjacent pitch errors.

The straightness of the slides on the bed and vertical column is an absolute necessity and for this purpose an autocollimator, with a mirror mounted on a suitable bracket, is used. This is indicated in Figures 9 and 10. It is also vital to ensure parallelism of the hob saddle motion with the work axis. The method normally used to establish parallelism is to mount a ground bar or pillar on the table. A sensitive indicator, carried on a suitable bracket attached to the saddle, is traversed along the side of the pillar and another one is located in a plane at right-angles to prove the alignment both in the plane containing the hob saddle and the one at right-angles to it. This alignment, in the case of a vertical-axis hobbing machine for wheels, is checked in three positions, one corresponding to the closest approach of the hob to the work axis, another at its most distant position and the third at an intermediate point. In the case of a pinion machine, this bar is mounted between centers.

Another method is to use an autocollimator and right-angle prism, in conjunction with a reflecting mirror in a bracket which can be carried on the hob saddle guides, as indicated in Figure 10. It is necessary to take readings at several positions across the surface of the table and at different distances from the hob saddles guides and then to rotate the table through 180 degrees and take another set of readings from which the mean position of the table axis is determined. The autocollimator is then set at this mean position and readings are taken at different positions along the column guideways without disturbing the autocollimator.

Yet another method is to suspend a fine steel wire from a suitable bracket, the wire being held straight by a weight at its lower end, which is immersed in an oil bath to damp out lateral oscillations. Two micrometers are set up at right-angles to each other and make contact with this wire. It is preferable to use an electric circuit to indicate when the micrometers are just making contact with the wire. If the table axis is not vertical, a correction must be made in the interpretation of the micrometer measurements from the stretched wire which, of course, hangs in a truly vertical position.

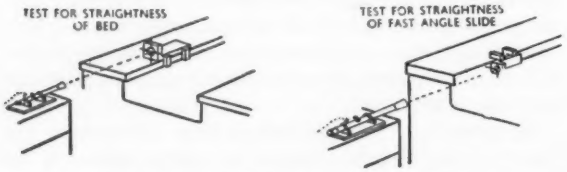


Figure 9. Testing bed slides for straightness.

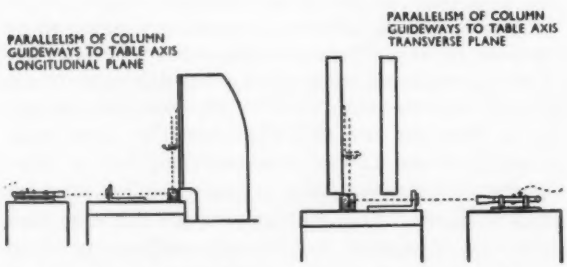

PARALLELISM OF COLUMN GUIDEWAYS TO TABLE AXIS LONGITUDINAL PLANE
PARALLELISM OF COLUMN GUIDEWAYS TO TABLE AXIS TRANSVERSE PLANE

Figure 10. Testing column with autocollimator and prism.

ALIGNMENT OF HOB SPINDLE SUPPORT

For this purpose a bar is mounted in the position of the hob arbor and the hob spindle is set vertically so as to avoid any deflection in the bar due to its own weight. A dial indicator operating from a stylus point is carried on the end of this bar. Rotation of the stylus within the hob spindle bearing and moving the bearing to different positions along its guides, verifies the alignment of the support in relation to the hob spindle axis.

A method originally evolved by the National Physical Laboratory is used for testing cyclic errors in the table motion. A smoked glass plate is mounted on the machine table or on the faceplate in the case of a horizontal pinion machine. A notched plate is mounted on the main dividing wormshaft when checking the relative motion of this wormshaft and the table, or on an extension of the hob spindle when checking the relative motion of the hob spindle and the work. A plate of this kind is illustrated at the top of Figure 11, while on the right at the bottom is shown a contact-breaker which is operated by the notched plate; this interrupts an electric circuit and operates the marker, shown at the bottom left of the figure, causing it to mark the smoked glass plate at positions corresponding to each notch or projection on the plate already described. Figure 12 shows this apparatus in use on a horizontal table

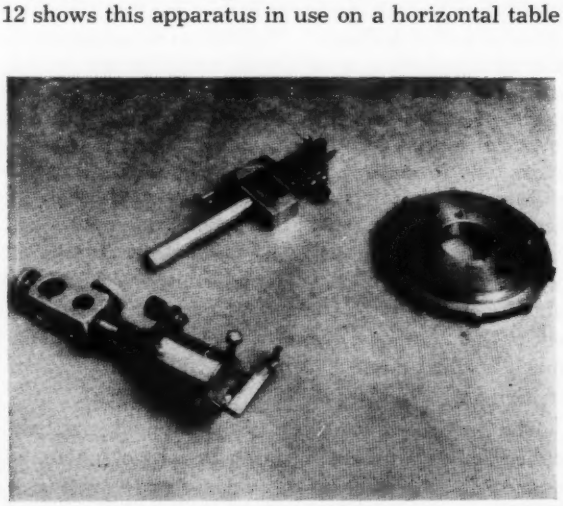


Figure 11. Apparatus for checking cyclic errors in table motion.

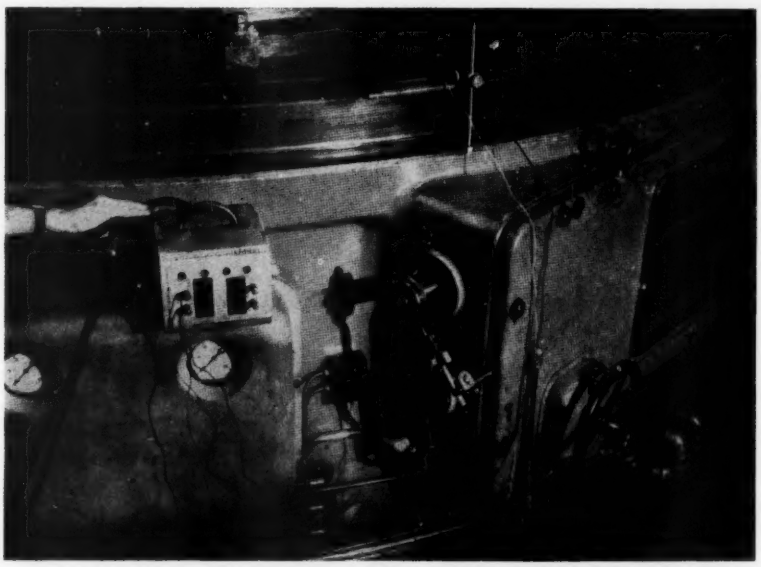


Figure 12. Apparatus in Figure 11 attached to master worm shaft.

with the notched plate mounted on an extension of the master wormshaft. The distances between the needle markings on the smoked plate are measured by means of a travelling microscope, and any irregular spacing between these marks is indicative of irregular movement of the table.

RATE OF HOB SADDLE MOTION WITH REFERENCE TO ANGULAR ROTATION OF FEED SCREW

There are several methods of checking the rate of hob saddle motion. One uses a notched disc located on the feed screw and a smoked glass plate mounted on the hob saddle, similar to that described above for cyclic errors in table motion. Where the distance traversed is considerable several plates may be necessary to cover the whole traverse.

Another method is to set the machine for a suitable rate of feed of the hob saddle and to support on the table, not necessarily at its center, a ground tube or bar, smoked on its outer surface. A needle, carried on the hob saddle, comes into contact with the smoked tube during each revolution of the table and the distances between successive marks are measured by means of a travelling microscope.

A third method, devised by the Mechanical Engineering Research Laboratory, uses a camera, the shutter of which remains open and which is loaded with a "slow" plate. This camera is carried on the hob saddle and is focused on a glass scale marked in suitable increments slightly different from the pitch of the lead screw. Illumination is provided by a lamp which is triggered by a finger on the end of the lead screw. Successive flashes are thus recorded on the photographic plate as lines a small distance apart. Any variation from the intended distance can again be measured with the travelling microscope.

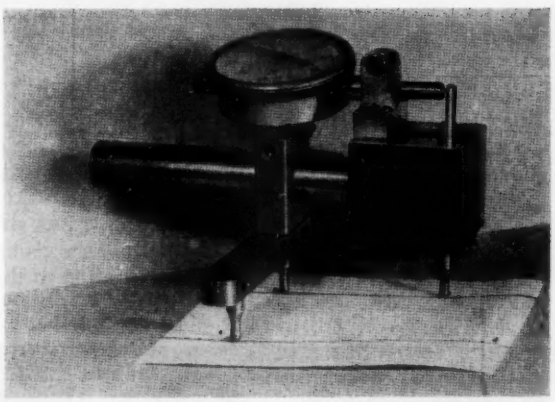


Figure 13. Hand-operated pitchometer for checking test gear on machine.

TEST WHEELS

It is the practice to cut a spur test wheel for checking the accuracy of indexing of every precision hobbing machine supplied, and to supply two helical test wheels, right and left hand, to prove the correctness of axial pitch and limitation of wave errors. The checking of such gears in the case of the spur wheel for indexing can be carried out as described above by the retractable pitchometer, while the gear is still mounted on the machine, or it can be done by a hand-operated instrument, as shown in Figure 13.

The helical test gear is checked for undulations by

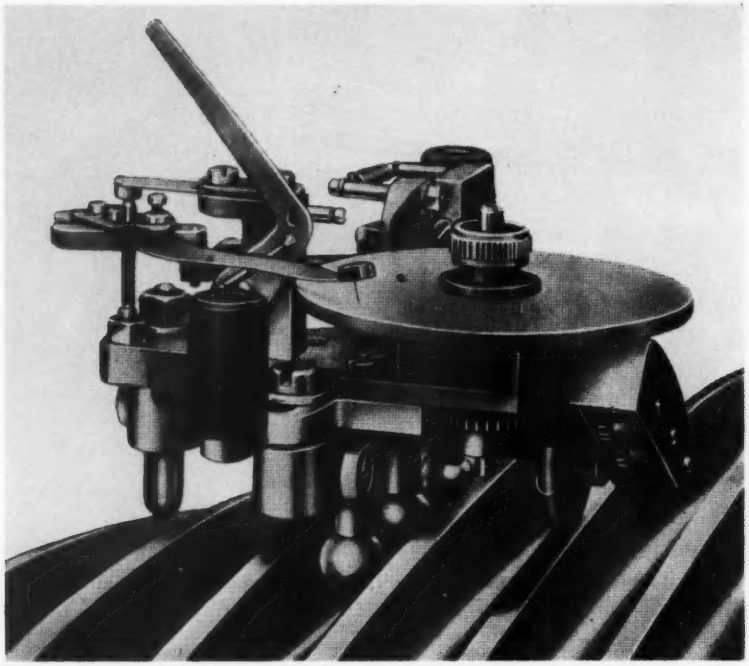


Figure 14. Tomlinson wave meter.

means of the Tomlinson wave-meter, Figure 14. This has two ball-ended feet which rest in a tooth space, and situated midway between them is a ball-ended stylus of similar diameter, but set a little further from the root of the tooth so that it makes contact on one side of the tooth space only. As the instrument is traversed along the length of the tooth, the movement of the center ball with relation to the line passing between the two feet is indicated, with a large degree of magnification, on a smoked plate which is caused to rotate by a small friction wheel operating on top of the tooth.

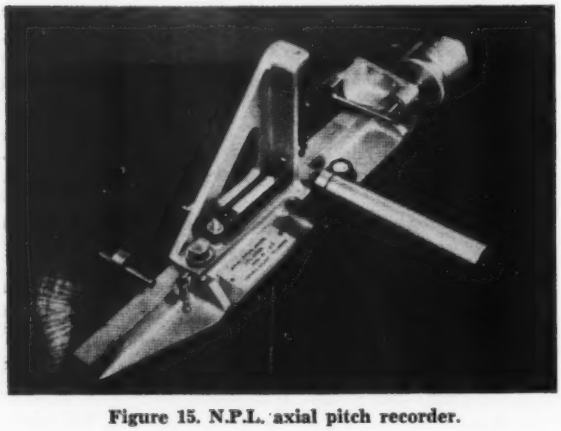


Figure 15. N.P.L. axial pitch recorder.

The test gear is also checked by a National Physical Laboratory axial pitch recorder, Figure 15. This can be used with the gear set in either the horizontal or a vertical position. Two ball-ended fingers are set at a distance corresponding to the axial pitch by means of standard gauge blocks, with the micrometer, shown at the right-hand end of the instrument, set at zero. When using this in, say, the horizontal position with the axis of the gear horizontal and correct axial pitch, the spirit level near the center of the instrument will rest in its central position. If, by any chance, the axis of the gear is not perfectly horizontal, the spirit level can be set to give its mean reading by means of a screw adjustment and a controlling spring near the left-hand end. When taking readings the micrometer dial is adjusted so as to place the spirit level in its mean position. The movement of the micrometer is therefore a measure of the error in axial pitch. When taking readings with the axis in a vertical position another spirit level is provided which is set at right-angles to the one already mentioned.

J. H. POTTER

THE GAY-LUSSAC FREE EXPANSION EXPERIMENT

THE AUTHOR

was born in the City of New York and was educated at Columbia and at the Johns Hopkins University. In addition to five years in the chemical and shipbuilding fields, he has had nineteen years of experience in research and teaching at the university level. He has filled academic assignments at Johns Hopkins, the University of Illinois, and at the Stevens Institute of Technology. Since 1955 he has been Dean of Graduate Studies at the latter institution. He has been a corporate member of the A.S.M.E. for twenty years, and has contributed several other papers to the JOURNAL.

SUMMARY

Gay-Lussac reported on what was probably the first non-flow, free expansion experiment on gases a century and a half ago. The implications in his work proved more valuable than the data, lighting the way for men like Joule and Kelvin.

Gay-Lussac's experiment was repeated with modern instrumentation. Some interesting phenomena were brought to light which will form the basis for further experimental studies.

INTRODUCTION

THE YEAR 1957 marked the 150th anniversary of the publication, in the Mémoires d'Arcueil, of the Gay-Lussac free expansion experiment.[1] This research involved the non-flow expansion of several test gases between two glass flasks, one of which was originally at atmospheric pressure and the other originally evacuated.

As this was an important milestone in the development of the science of thermodynamics, it is fitting that this significant anniversary be observed. The present paper reviews the work of Gay-Lussac and describes apparatus built and operated in much the same manner as that of the famous French scientist. However, modern instrumentation provided information on the transient phenomena.

THEORY

Nomenclature:

Symbols used in the paper are identified below. Subscript numbers refer to variables with respect to the opening of the valve:

P = pressure, mm. Hg.
T = Temperature, °K.
t = time, seconds
γ = ratio of specific heats, C_p/C_v

At room conditions many real gases approximate ideal gas behavior. This is particularly true of the diatomic gases. When some gas is suddenly withdrawn from an adiabatic vessel, it has been believed that the gas that remains in the vessel undergoes adiabatic expansion accompanied by a drop in temperature. If as a first approximation, the expansion

is considered to be reversible, then:

$$T_2/T_1 = (P_2/P_1)^{\frac{\gamma-1}{\gamma}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Consider two adiabatic vessels joined by a line containing a quick-opening, loss-free, adiabatic valve, and instrumented for instantaneous measurements of pressure and temperature. If one of the vessels is charged with gas and the other is almost evacuated, but contains trace amounts of the gas under test, a theoretical Gay-Lussac arrangement is realized.

Upon opening the valve, gas rushes into the evacuated tank. The gas remaining in the first vessel undergoes expansion, and the temperature drops sharply. The pressure difference between the tanks accelerates the gas which is transferred, imparting to it a certain mean velocity. In the receiving vessel the kinetic energy of the entering gas is dissipated, and is converted to internal energy. This is accompanied by a rise in temperature.

If the thermodynamic system is considered to include both vessels and the connecting piping, and as no external work is done, the First Law requires that the internal energy of the system shall be conserved. As the system is closed, the mass of the system also remains constant. From these two considerations the necessary calculations may be made for the events which take place in each of the vessels.

If the connecting valve is closed at the time that pressure equilibrium is established, the theoretical temperature in each vessel would remain that at the end of the expansion. If the connecting valve were left open, diffusion would take place and the same final temperature would be found in both tanks.

The presence of irreversible processes makes it impossible to realize the conditions cited above in any real apparatus. Fluid friction and heat transfer are present to some extent in each part of the experiment, and each tends to vitiate the theoretical possibilities.

A conjectural time-temperature plot is shown schematically in Figure 1. Here it is assumed that at time zero the instantaneous expansion has taken place, with the temperatures in the two vessels at the maximum and minimum values shown on the vertical axis, and that the valve connecting the tanks has been closed. As a result of heat transfer, each of the vessel temperatures tends to approach

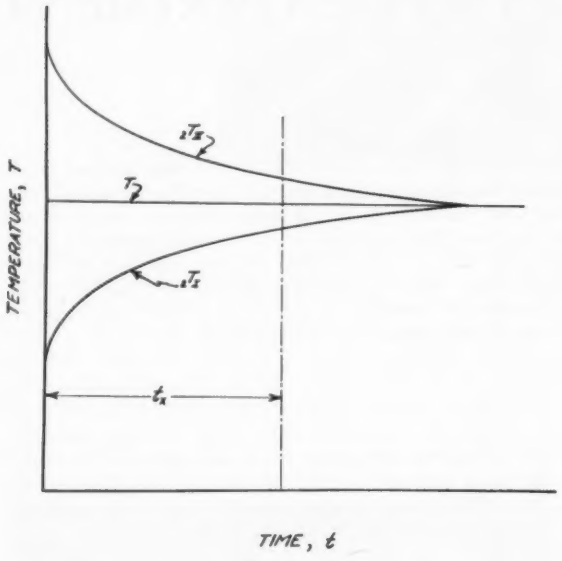


Figure 1.

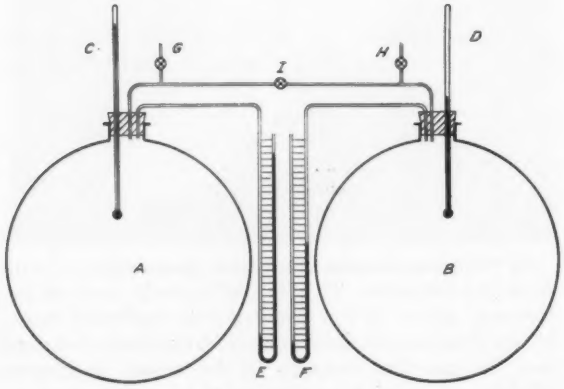


Figure 2.

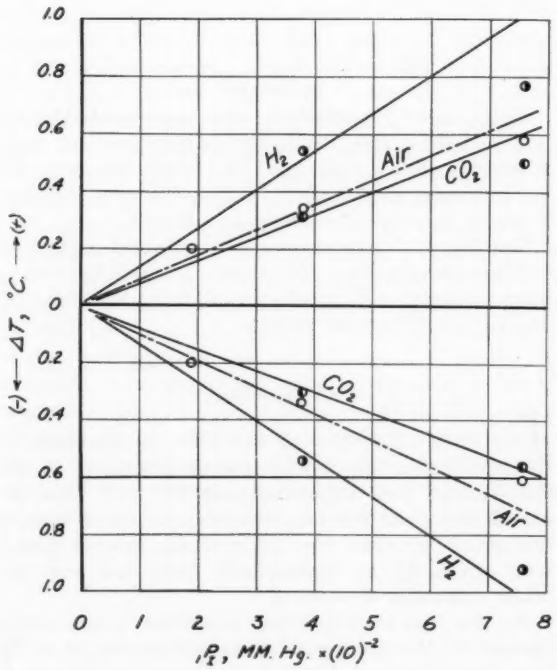


Figure 3.

TABLE I

Gas Density expressed in Barometer	Temperature Change, ° C.							
	Air		H_2		CO_2		O_2	
	Tank A	Tank B	Tank A	Tank B	Tank A	Tank B	Tank A	Tank B
760	−0.61	0.58	−0.92	0.77	−0.56	0.50	−0.58	0.56
380	−0.34	0.34	−0.54	0.54	−0.30	0.31	−0.31	0.32
190	−0.20	0.20	—	—	—	—	—	—

the ambient temperature. At a time, t_x, after expansion, the tank temperatures are as indicated in Figure 1.

From a reading of the original Gay-Lussac paper, it is apparent that he had no knowledge of equation (1), nor very much appreciation of the heat transfer effects suggested in Figure 1. He believed that the temperature changes were directly proportional to the gas densities involved.

Gay-Lussac performed his experiments with two 12-litre glass balloon flasks, arranged as shown in Figure 2. A sensitive alcohol thermometer was placed in each flask, and a lead pipe was used to connect the two vessels. To remove moisture from the gas samples some calcium chloride was placed in each flask.

Both vessels were evacuated, then Tank A was filled with gas at atmospheric pressure. To ensure thermal equilibrium the two flasks were isolated and left undisturbed for 12 hours. The lead line was then opened, and the pressure fell to about half the original value. He estimated that about two minutes were required to reach pressure equilibrium.

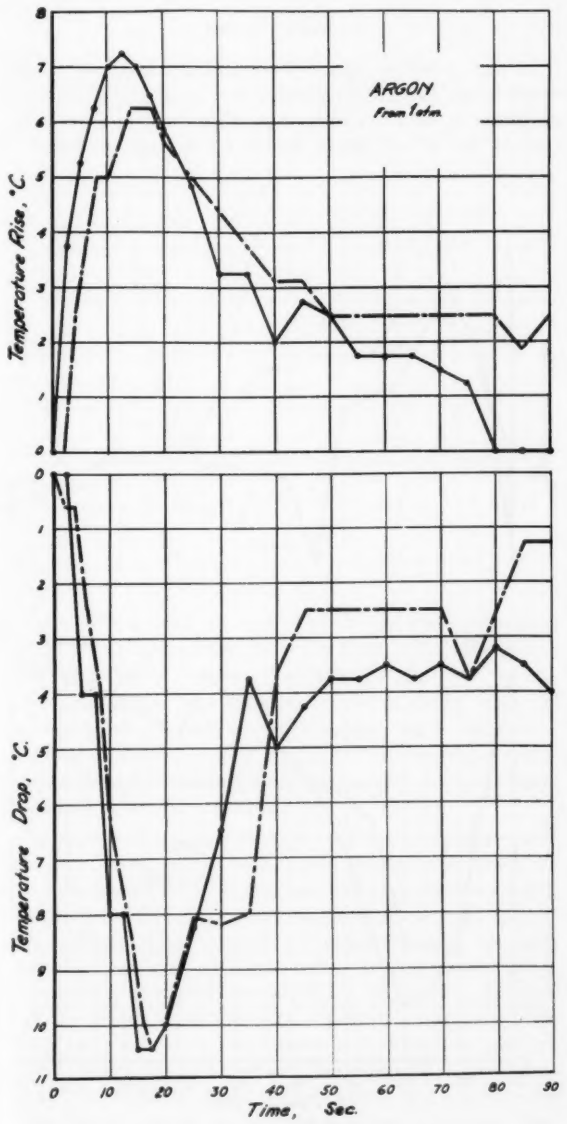


Figure 4.

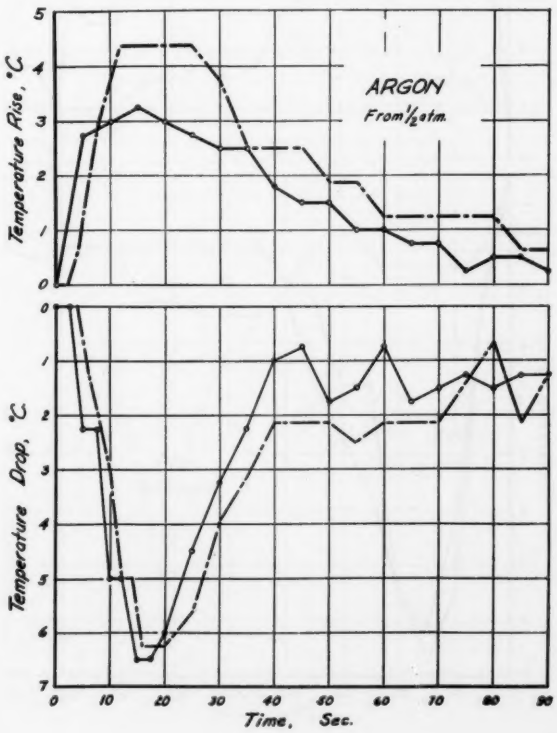


Figure 5.

He found that the temperature drop in the high pressure vessel and the temperature rise in the low pressure flask were nearly equal. These data are reported in Table I.

After closing the valve, the low pressure vessel was evacuated again, and the process was repeated. This was done for pressure reductions to ½, ¼, ⅛, and 1/16 of the original atmosphere. The Gay-Lussac data for hydrogen, carbon dioxide and air are plotted in Figure 3. The ordinate represents the difference in temperature between the ambient and the final temperatures in the vessels. The upper plots show the temperature change in the low pressure tank, the lower curves represent the cooling in the high pressure tank. The abscissa is the original pressure in the high pressure vessel; the horizontal distance between any two points represents the pressure drop required to effect the corresponding change in temperature. It is to be noted that as the pressure drops decreased there was an improvement in the agreement between the temperature change due to expansion and that due to compression and mixing. This was probably due to a reduction in the heat transfer losses as the initial terminal temperatures more nearly approached the ambient temperature.

One run was reported in which an air thermometer was used. This indicated temperature changes about eight times as great as those measured with the alcohol thermometer. The data in Table I, however, represents alcohol thermometer measurements.

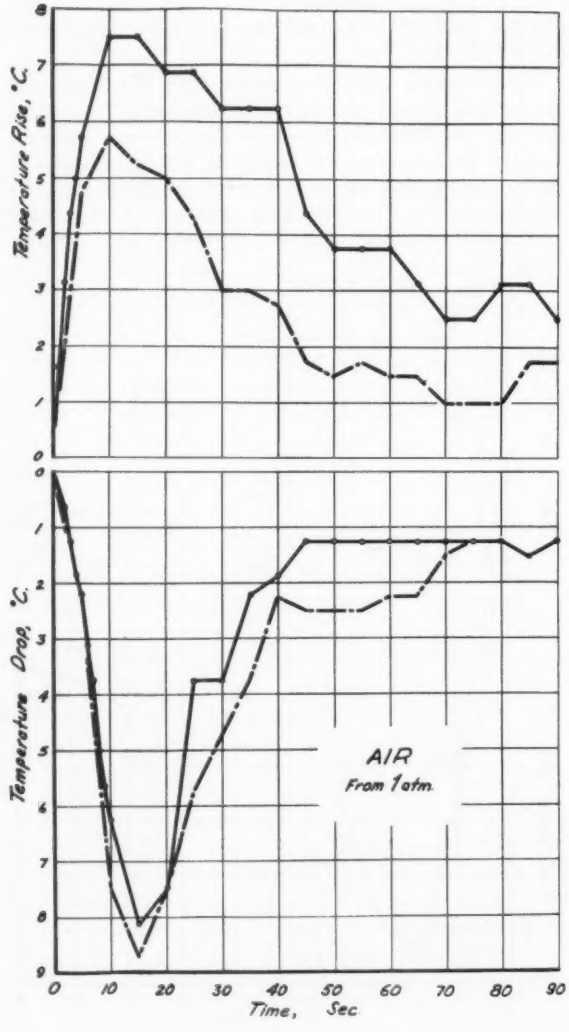


Figure 6.

CURRENT WORK

In the present work two 12-litre balloon flasks were used. Each contained a few crystals of calcium sulphate to dessicate the gas. The vessels were connected by a ¼" glass manifold which included a

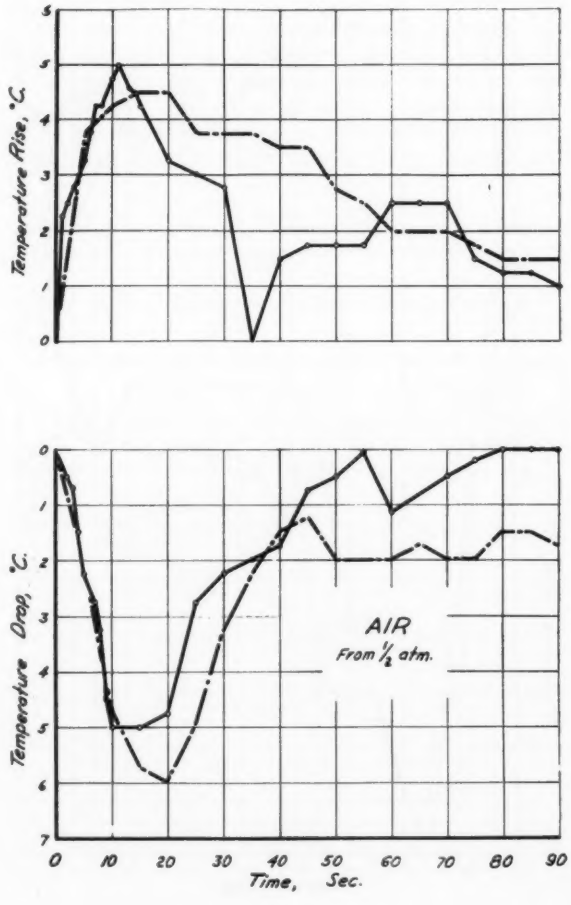


Figure 7.

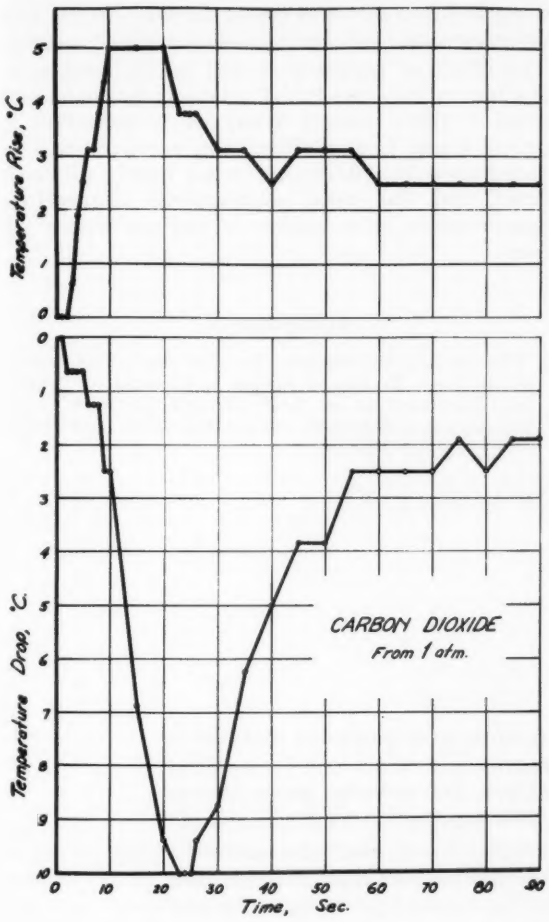


Figure 8.

master valve, and valved branch lines for charging the vessels. Each flask was covered with aluminum foil to minimize radiation losses.

Temperature measurements were made with 28 ga. chromel-alumel thermocouples, one being located at the center of each flask. The thermocouples were connected through high-grain D. C. amplifiers to Brush recording charts.

Each vessel was connected to a mercury manometer, and in addition a McLeod gauge was used on the low pressure side to measure the extent of the evacuation. The test gases were commercial Argon and carbon dioxide and atmospheric air. In each case the gas was passed over a drying agent prior to entering the test vessel. With one tank charged and the other evacuated to about 0.3 mm. Hg., the temperatures were read over an extended period. When there was agreement between the gas temperatures and the room temperature, the connecting valve was opened until pressure equalization had taken place. Subsequently the test was repeated starting with about half an atmosphere pressure on the high side.

RESULTS AND DISCUSSION

Time-temperature plots are shown for the three test gases in Figures 4 through 9. Where repeat runs were made these are shown as broken lines. In all cases the temperature drop in the high pressure vessel exceeded the temperature rise in the low pressure vessel. In the cases of air and CO_2 the maximum temperature rise is of the order of ten times as great as the values reported by Gay-Lussac. Also the integrated values of temperatures over the time ranges are greater than those he reported. This gives support to the one measurement he had made with the air thermometer, as being indeed the most accurate.

Fluid flow considerations will show that sonic velocity was attained early in the mass transfer process. This and the fact that the vessels and connecting piping were not adiabatic, accounts for the time lag in the temperature rise curves. In the majority of cases the maximum temperature was reached about 15 seconds after opening the valve.

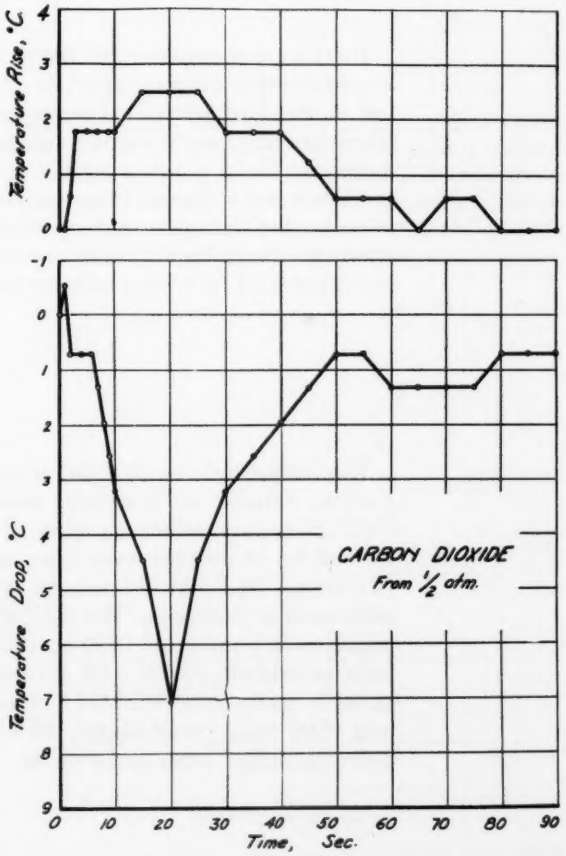


Figure 9.

The most striking feature was the fact that in the cooling of the gas in the high pressure vessel the temperatures fell far short of the values predicted from equation (1). As the initial gas temperature was the same as the ambient temperature it is improbable that radiation had much influence on the cooling rate of the gas. It is probable that the location of the thermocouple had a strong bearing on the temperature rise on the low pressure tank. This is explainable in terms of the high state of turbulence to be expected. However, some analogous situation must have occurred in the high pressure tank as well as the heat transfer mechanisms known to be at work.

CONCLUSIONS

(1) As an academic exercise it was both interesting and instructive to repeat the Gay-Lussac free expansion experiment with modern instrumentation.

(2) Further experiments will be undertaken in an effort to learn the P-V-T relations that exist in a vessel of finite volume when gas is permitted to expand freely from it. Particular emphasis will be placed upon (a) obtaining a more nearly adiabatic vessel, and (b) upon simultaneous temperature measurements at a number of stations within the vessel.

BIBLIOGRAPHY

1. "First Attempt to Determine the Changes in Temperature which Gases Experience Owing to Changes of Density, and Considerations on their Capacity for Heat." L. J. Gay-Lussac, MEMOIRES DE LA SOCIETE D'ARCUEIL, Vol. 1, 1807, p. 180.

Increasing recognition of the value of gold as an engineering material is a consequence of the properties which have made it valuable in the past for use in the fine arts. Cost remains a problem, but extreme performance requirements make it a good competitor with many other exotic, high-cost materials. Gold is being used in nuclear reactor lining, electrical contacts, terminals and switches. New vacuum techniques have enabled it to be used in controlled thickness coatings which will reflect some light frequencies and transmit others. Its high heat reflectivity is useful in coatings on missile surfaces exposed to intense exhaust heat of the motors.

—from PRODUCT ENGINEERING
August 10, 1959

The Soviet Submarine Fleet is believed to have about 60 "Z" class submarines capable of launching missiles from inside tubes, and about 100 "W" class submarines capable of deck-launching air breathing missiles. Two series of missiles have been under development. The GOLEM I is a two-stage, liquid-fueled missile, descended from the V-2, with a range estimated at 400 miles. The GOLEM II is a larger two-stage, liquid-fueled missile with a range of 1200 to 1500 miles. The GOLEM III is a two-stage, solid-propellant missile with a range of 1500 to 2000 miles. The second series is made up of KOMET I, II and III, having ranges of about 100, 500, and 1500 miles respectively. All are solid fueled and may be capable of being launched from underwater.

—from MISSILES AND ROCKETS
August 1959

"THE CHARTERED MECHANICAL ENGINEER"

SOME ENGINEERING ASPECTS OF HIGH-PERFORMANCE AIRCRAFT

ACKNOWLEDGEMENT

Published in the June 1959 edition of "The Chartered Mechanical Engineer," this article was written by Mr. E. Ellam.

INTRODUCTION

THE FUNDAMENTAL PROBLEMS of aeronautical engineering are those of keeping weight and bulk to a minimum while retaining satisfactory strength and operational reliability. This latter point is particularly noteworthy: in an aircraft there is no such thing as merely "pulling into the side" if something fails.

The advent of aircraft whose operating life is spent at very high speeds and altitudes accentuates these problems, since the aerodynamic shapes required to minimize drag and to ensure satisfactory stability and controllability are far from ideal when viewed from the standpoint of the engineer.

The difficulties which the engineer is required to overcome may be broadly divided into three groups—structural, mechanical and physiological. Since all these difficulties arise directly from aerodynamic causes, it may be pertinent to discuss briefly some of the aerodynamic effects of high-speed, high-altitude flight.

AERODYNAMIC CONSIDERATIONS

Drag Rise and Shock Stall

The force opposing the motion of an aircraft is called "drag"; it arises in a number of ways, and at low speeds—up to about 450 mile/hour—it varies as the square of the speed. However, as the speed of the aircraft approaches that of sound, the drag starts to rise more rapidly than this and as the speed of sound is passed (Mach number = (airplane speed) / (speed of sound) = 1.0) the rate of increase of drag tends to return to its low speed value. This variation is shown in Figure 1, which also shows the corresponding variation of the lifting force on the aircraft.

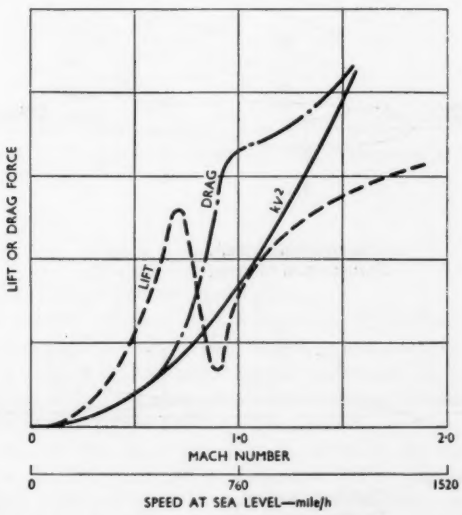


Figure 1. Variation of Lift and Drag Forces with Mach Number.

This rise in the rate of increase of drag with speed is due to the formation of "shock-waves" around the aircraft: in passing through the shock-wave the air is rapidly compressed, the work of compression being extracted from the aircraft in the form of an additional drag component called "wave drag."

The point at which this severe drag rise starts is called the "critical Mach number," and is also marked by the occurrence of a number of other phenomena: there is a sudden loss of lift, together with a pitching of the aircraft, which may be violent. The cumulative effect is similar to the low-speed "stall" or loss of lift, and is thus sometimes called the "shock stall": on subsonic aircraft it marks the upper limit of performance.

Shape of the Aircraft

At supersonic speeds, wave drag is the predominant drag component, and the need to minimize it may affect the shape of the aircraft in a number of ways.

For instance, Figure 2 shows the forces acting on an aircraft in straight level flight. The center of gravity is, in most conditions, in front of the point of action of the lift, so that in conventional aircraft (Figure 2*a*) the tail must supply a download L to balance the resulting nose-down couple.

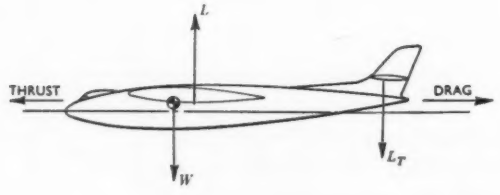
In some instances L may be as much as $0.2W$, which greatly increases the lift required from the wings. This, in turn, increases the wave drag. If, now, the "tailplane" is mounted ahead of the wing (Figure 2*b*) L assists the main wing lift and a considerable reduction in wave drag results. Thus the supersonic aircraft may well fly "tail-first."

The effects of the shock stall may be minimized by the use of very thin wings, or wings having sweptback leading edges, or both. However, at supersonic speeds approaching Mach 2 (1320 mile/hour at 36,000 ft.), the degree of sweepback required becomes excessive, and a tendency towards straight wings of small thickness-chord ratio (4 per cent or less) is evident, as shown by the Lockheed F-104.

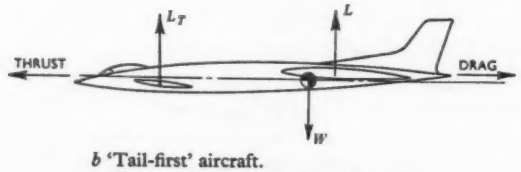
Some possible configurations for high-speed aircraft are shown in Figure 3. In all these cases the wings are useless as stowage space for either the undercarriage or the engines. Also, to achieve a given range more fuel is required, most of which must be carried in the fuselage. A fat fuselage increases the wave drag; a common feature is thus likely to be a long, slender fuselage with length/diameter ratio of 18 or more.

A number of engine positions is also possible. Figure 3*a* shows a delta wing having 70° of sweepback and the engines suspended below the wing in "pods." Figure 3*b* is a typical "tail-first" machine with the engines nestled alongside the fuselage, while Figure 3*c* shows engines mounted at the tips of very thin straight wings. All these arrangements increase the wave drag of the aircraft and all have their champions. Many more combinations are possible, but Figure 3 contains most of the basic features.

At speeds higher than that corresponding to the

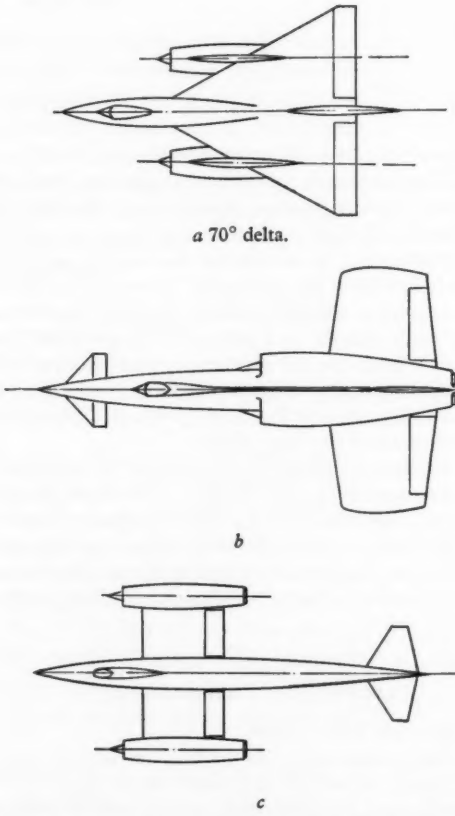


a Conventional aircraft.
Thrust equal to drag; $L = W + L_T$



b 'Tail-first' aircraft.
Thrust equal to drag; $L = W - L_T$

Figure 2. Forces on an Aircraft in Steady Level Flight.



a 70° delta.

b

c

Figure 3. Some Possible Configurations for High-performance Aircraft.

critical Mach number controls lose their effectiveness and become harder to move for a given angular deflection. Supersonic aircraft may, therefore, have control surfaces somewhat larger than those used at present, and some form of power assistance for the pilot is inevitable.

Effects of Altitude

The shock stall and the drag peak always occur at the same Mach number for a given aircraft, and as the speed of sound decreases from 760 mile/hour at sea level to about 660 mile/hour at 36,000 ft., it follows that the speeds corresponding to these effects also decrease with increasing altitude. This reduction in the speed of sound is due to the reduction in temperature with increasing altitude, but the pressure and density are also reduced.

These quantities affect the engine power and the aircraft drag, and hence the aircraft's top speed, which decreases with increasing altitude. The minimum speed at which flight is possible ("stalling speed") varies inversely as the square root of the air density, and increases with altitude. The maximum and minimum speeds of the aircraft thus approach each other as the altitude increases, and the ultimate limit of the aircraft's performance is reached when the two become equal. This variation is shown in Figure 4 for a typical "just supersonic" aircraft. The increase in maximum speed between 25,000 and 50,000 ft. is due to the use, at those altitudes, of "reheat" —a method of augmenting the jet engine thrust by burning additional fuel aft of the turbine.

Heating Effects

At some points on the aircraft, called "stagnation points," there is no relative velocity between the air and the aircraft. The loss in kinetic energy of the air at these points appears as heat, resulting in a temperature rise approximately proportional to the square of the speed (and hence of Mach number). This temperature rise is about 60°C at 750 mile/hour and 225°C at 1500 mile/hour at sea level, and is measured relative to the ambient temperature: thus, the final temperature attained by the aircraft depends to a large extent upon the conditions under which it operates. The whole aircraft does not attain this temperature, but "mean" values of 85 per cent or so of this temperature are not impossible.

Figure 5 shows the variation with Mach number and height of an insulated skin, that is, a skin from which no heat is assumed to be lost. This is rather more severe than the practical case in which skin frictional effects tend to increase the temperature, while radiation and conduction to the interior of the aircraft tend to reduce it. The most recent work in this field indicates that radiation from the exterior of the aircraft can lead to a significant reduction in the temperatures at which high-speed aircraft will be called upon to operate.

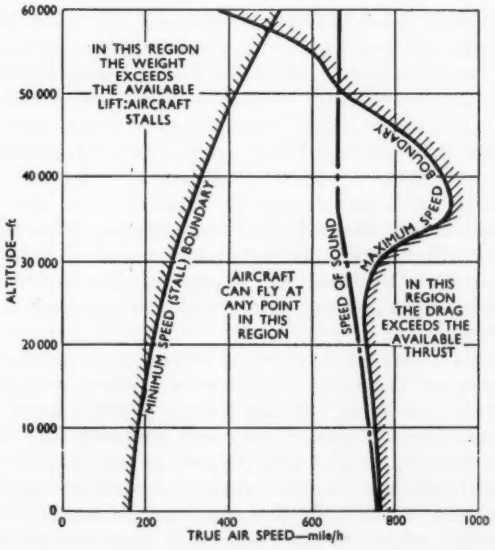


Figure 4. Flight Boundaries for a Typical Transonic Aircraft.

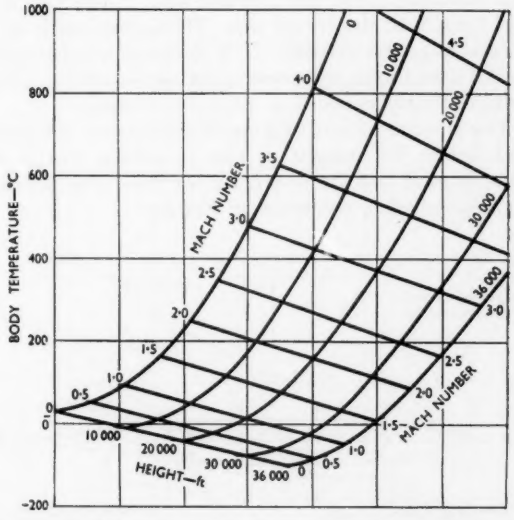


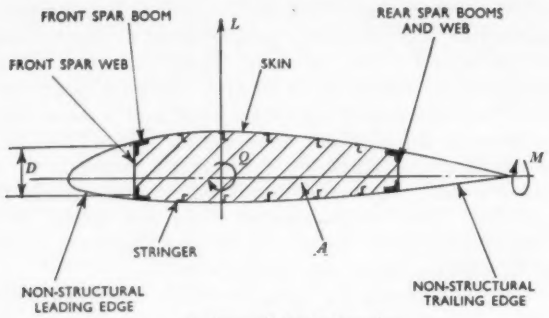
Figure 5. Variation of Insulated Skin Temperature with Mach Number and Height.

THE STRUCTURAL PROBLEM

Effects of Geometrical Limitations

The advent of very thin wings and other surfaces makes strength and stiffness requirements very difficult to meet without imposing an unacceptably large weight penalty, since it is then impossible to make the most efficient use of the material.

Consider the low-speed wing section shown in Figure 6. The section is subjected to a span-wise bending moment M, a torque Q and a vertical shear force L. The torque and the vertical shear force are together resisted as shear stresses in the skins and

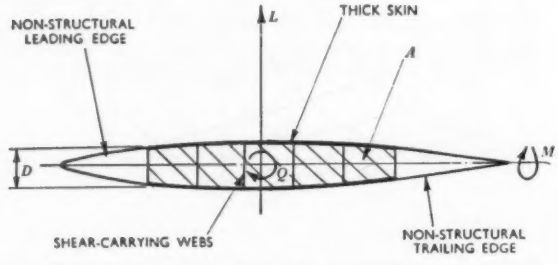


A Area of shaded portion.
L Lift force.
M Bending moment.
Q Torque.

Figure 6. Typical Low-speed Wing Structure.

spar webs, the shear stresses for a given torque and skin thickness being inversely proportional to the shaded area *A*. The bending moment is resisted as end loads in the spar booms, stringers and skins: for this example these are compressive in the top skin and tensile in the lower one. These end loads vary inversely as the distance *D*. The stringers also serve to stabilize the skins, preventing the buckling which would otherwise occur at very low stresses.

The amount of material required to carry the loads, and hence the weight of the structure, varies inversely as *A* and *D*. Now consider the corresponding high-speed wing structure in Figure 7.

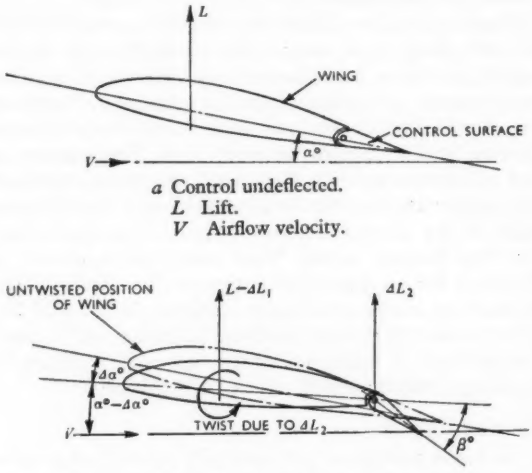


A Area of shaded portion.
L Lift force.
M Bending moment.
Q Torque.

Figure 7. Typical High-speed Wing Structure.

End loads due to bending are now carried largely in the skins, the stringers and "booms" serving mainly to attach the shear webs to the skins. *A* and *D* are both reduced, necessitating thicker skins and spar webs, and thus a heavier structure. The multiple webs serve to stabilize the skins and to provide the area required to carry the vertical shear force.

In addition, the torsional stiffness of the wing varies directly as the area *A* and the skin thickness. This is an important factor in preventing "aileron reversal." Deflection of a control at the trailing edge twists the wing so that the change of wing lift opposes the force due to the deflection of the control itself, as shown in Figure 8. This effect increases with increasing speed, and at some speed known as "reversal speed" the two forces exactly cancel out. At higher speeds the control is effectively reversed. Only the provision of adequate stiffness can prevent this phenomenon from occurring within the operational speed range of the aircraft, and if *A* is small the skin may have to be thicker than that needed to meet the strength requirements, thus adding a further weight penalty. This type of control reversal may also be encountered on tail surfaces, although this is more uncommon.



a Control undeflected.
L Lift.
V Airflow velocity.

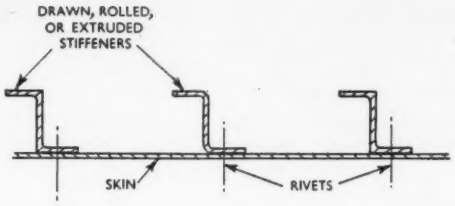
Figure 8. Wing Twist due to Control Loads.

In very thin wings it may be found that the bulk of aluminum alloy required to carry a given load places the centroidal axes of the skins too close together (i.e., *D* too small) for economic usage of the material, and some other denser but stronger material (for example, stainless steel) may give a lighter structure.

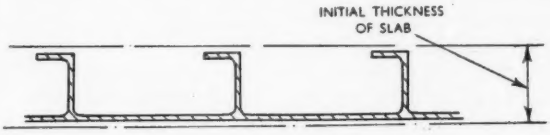
Some novel forms of construction must be considered for such structures. Among these are the machining of integral skins and stiffeners from large slabs (Figure 9), casting the surfaces in steel or light alloy followed by machining and, for small wings and tailplanes, machining entirely from solid material.

Also available are those forms of construction known as "sandwich construction," which make use of two thin skins stabilized by a "core" placed between them, to which they are attached. The core may be balsa wood, a plastic foam, or one of two types of metallic core: for the higher-temperature applications only the metallic forms are important. The non-metallic cores are normally only used for internal partitions and other "non-structural" duties.

The two types of metal core are (1) "honeycomb,"



a Riveted (conventional) skin.



b Machined (integral) skin.

Figure 9. Types of Skin Construction.

in which a hexagonal core of very thin foil is formed and bonded by some means to the facing skins (Figure 10*a*) or (2) a corrugated sheet spot-welded to the outer skin and blind-riveted to the inner one. (Figure 10*b*).

The advantages claimed for sandwich construction are that buckling of the facing skins is delayed almost until the material fails in shear or compression, and that such skins retain their aerodynamic shape well under load. In addition, a corrugated core assists the facing skins in carrying end loads in one direction. The efficiency of the honeycomb panel depends very largely upon the quality of the bond between the facing skins and the core, and it is difficult to guarantee this by inspection. In order to make use of either of these constructional methods, considerable expenditure on special equipments is necessary.

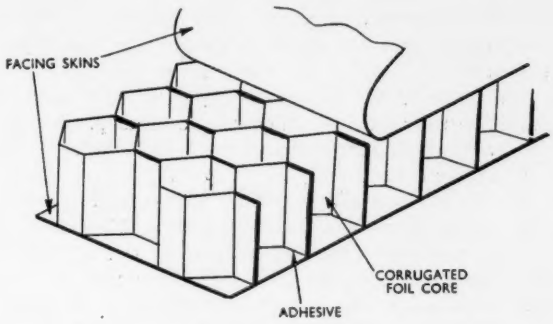
In very thin structures the use of sandwich panels tends to reduce the distance D and may thus reduce the efficiency of the structure. The detail design of joints between panels is also critical, and great care must be exercised if excessive weight is to be avoided.

Effects of Temperature

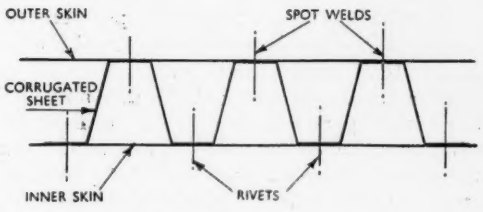
The first problem arising from high temperatures is that of "thermal stresses," due to differences in temperature (and, possibly, materials) throughout the structure resulting in differential expansions. Unless suitable precautions are taken, these stresses may equal or exceed those resulting from normal flight loads on the aircraft, thus necessitating an increase of strength and structure weight.

Among the more obvious remedies are the designing of joints to have good thermal conductivity as well as mechanical strength, in order to reduce temperature gradients as much as possible, the use of similiar materials throughout the structure, and the avoidance of sharp changes of section.

Other remedies which have been, or are being, investigated are the insulation or cooling of the structure, but development is still at an early stage.



a 'Honeycomb' core.



b Corrugated core.

Figure 10. Types of Sandwich Panel.

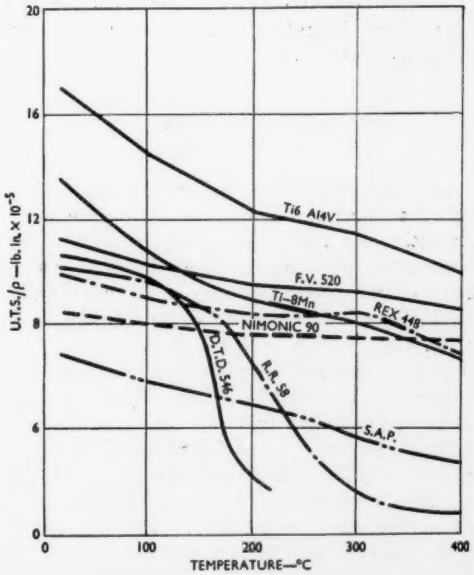


Figure 11. Specific Strength against Temperature, 1000 hours soak.

Figure 11 illustrates the variation in specific tensile strength with temperature, after 1000 hours of heat-

ing, for a selection of engineering materials, and is based on information given in a lecture to the Royal Aeronautical Society by Professor A. J. Murphy. It will be seen that all lose strength with increasing temperature, and the other mechanical properties (for example, Young's modulus) tend to deteriorate in a similar manner.

The aluminum alloys D.T.D. 546—a widely used structural material—and RR. 58 have lost 20 per cent of their room temperature properties at 150°C and 175°C respectively. Above 175°C the nickel-chromium-cobalt alloy Nimonic 90 and the steels Rex 448 and FV. 520 are all superior to the aluminum alloys —FV. 520, in fact, has a better specific tensile strength throughout the range.

The new material S.A.P. (sintered aluminum powder), while having only 40—50 per cent of the properties of the steels, is superior to the conventional aluminum alloys above 300°C.

The titanium-based materials Ti-8Mn and Ti-6A1-4V are both superior to the aluminum alloys at all temperatures, and to the steels at low temperatures. At the higher temperatures Ti-6A1-4V retains its superiority, while Ti-8Mn is bettered by the FV. 520 steel above 150°C and by Nimonic 90 above 330°C. However, the price of titanium is still high and scrap reclamation difficult, although the problems of manipulation and machining are regarded, in some quarters, as no more difficult than those of stainless steel. It is still probable that high-speed aircraft will be built mainly of steel with titanium used in certain special applications only.

THE MECHANICAL PROBLEMS

Power Controls

In very large or very fast aircraft the control loads are such that the pilot is unable to operate the controls directly, and some means of mechanical actuation is required. The usual forms of actuator are hydraulic or electric servo-motors, the input being connected to the pilot's controls and the output to the control surface.

Hydraulic controls consist of a hydraulic jack connected to the control surface. Hydraulic power may be supplied either from a central pump driving all controls, or from a self-contained, electrically driven pump. The latter arrangement tends to be rather bulky, and in confined spaces the former may be the only solution, despite increased vulnerability to combat damage in military aircraft.

Electrical actuators usually comprise an electric motor driving, *via* a clutch and reduction gearbox, a screw-jack of the "recirculating ball" type. In general the weight and bulk tend to be somewhat greater than for hydraulic units.

On high-speed aircraft having very thin wings it may be necessary to install the power control units in fairings external to the wings. The drag of such fairings may be very high indeed, and some other solution is preferable. Push-pull rods from remote control units in the fuselage have been suggested, but lack of stiffness, and possible backlash militate against such a system. Another alternative is to drive the control surfaces through reduction gearboxes and screw-jacks from shafting running along the wing, again with the power source being carried in the fuselage.

Another problem raised by power operation of the controls is the provision of a "feel" for the pilot, who normally judges the loads applied to the aircraft by the control loads which he applies. These loads vary with control surface movement and with airspeed. One way of providing such a feel is to make the pilot work against a spring over which his mechanical advantage is varied by an airspeed sensing device. The variation of mechanical advantage is usually performed by a cam, which can be made to incorporate any desired law (Force α V, V^2, V^3, etc.).

Manual controls are normally simple: jamming and malfunctioning are rare. The introduction of complicated mechanical devices into the system poses the question of reliability—what steps are taken to guard against failure? First, servo-motors may be designed so that in the event of a failure the control surface slowly returns to a trailing position, but this is not always so, some aircraft being designed to handle satisfactorily with one section of a control surface jammed in a deflected position.

Secondly, the control system may be arranged so that the power control units can be disengaged from the control surfaces at will by the pilot, who takes over manual control. Although used at present this type of system appears likely to disappear as speeds increase further.

Thirdly, there is the device of "duplication"—to which there are two alternative approaches. Either the control surfaces may be fitted with duplicated servo-motors energized by separate power sources, or the control surfaces themselves may be divided, each portion having a single servo-motor, again fed from different power sources. In the first case, if one of the two units fails, the remaining one continues to move the surface at a rate depending upon the arrangement of the system. If the second unit is a standby, the surface moves at full rate with either unit: if both units normally share the load, then the surface moves at a reduced rate with one unit failed. In the second case, half the total surface area is still available for control. It will be appreciated that duplication of the power control units involves considerable penalties in weight and space, especially as some authorities consider that more than two units may be required for adequate safety on long-range aircraft.

Bearings

Normally, ball and roller bearings are used for control surface hinges, operating under very exacting conditions of high bearing pressure and low angular velocity, which results in considerable wear of balls (or rollers) and tracks. Under the very high control

surface loads likely to be encountered in the future, such bearings may be too bulky for enclosure within thin flying surfaces, and to avoid protuberances plain bearings, capable of being used at very high bearing pressures, may be employed.

Whatever types of bearing are used, lubrication is likely to be a problem. In the past, grease capable of operation at very low temperatures without freezing has been required. In the future, however, greases capable of efficient lubrication over a temperature range from arctic to 200°C or so will be called for. The future progress of the engineer in these fields will depend very much on that made by the oil technologists.

Undercarriages and Braking

The remaining major mechanical problem is that of the undercarriage. This is something of a nuisance, supporting the aircraft as it does, only during the time when it is on the ground, at a considerable cost in weight and space.

Generally, it will not be possible to retract the undercarriage into very thin wings. Where it is possible to do so, it will be essential to employ thinner section tires operating at very high pressures. Runway loading pressures are, therefore, going to increase—especially with higher aircraft weights—and this may be a serious matter if runway construction is to be kept within the bounds of economic feasibility.

Both runway loadings and undercarriage weights may be reduced by the use of multi-wheeled bogies, but this definitely eliminates the wings as a stowage space. The use of external fairings is possible, but may be unacceptable because of the resulting increase in drag. In some cases it may be possible to house the retracted undercarriage in an engine nacelle, with a consequent reduction in the drag penalty.

The alternative to these schemes is stowage in the fuselage, a solution adopted by the Boeing Company in the United States of America for the B47 and the B52. These undercarriages consist of a number of similar units carrying approximately equal proportions of the load, the aircraft being balanced laterally by light "outrigger" units retracting into the engine pods. Similar solutions seem to be increasingly likely in the future.

Intimately connected with the problems of the undercarriage are those of braking. Modern aircraft, having low aerodynamic drag and considerable inertia, decelerate slowly. In addition, at touchdown, the wings are still supporing a large proportion of the aircraft's weight, thus reducing the friction force available for braking.

The first step towards a solution is the provision of some form of aerodynamic braking. This may be a parachute, streamed on touchdown, which produces drag only. Airbrakes in the wings or fuselage may also be opened, wing airbrakes having the advantage that they destroy wing lift in addition to producing drag, which transfers load to the wheels.

Wheel braking presents several problems, chief of which is overheating of the tires. This reduces the life of the tires, and may lead to blow-outs in service. Skidding is no longer a problem since the introduction of the Dunlop "Maxaret" unit which senses an incipient skid and relaxes the brake pressure accordingly. Attempts have been made to solve the overheating problem by placing the heat sink outside the aircraft, but these have so far met with little success. The only solutions immediately apparent are stouter tires and more efficient cooling of the brakes.

THE PHYSIOLOGICAL PROBLEM

Air Conditioning

At skin temperatures of 150°C and upwards, unless the flight duration is less than five minutes, satisfactory cabin conditions cannot be maintained by the use of insulated walls alone, and hence some means of supplying the cabin with refrigerated air must be evolved. In addition, at high altitudes, the air must be supplied at a pressure considerably higher than that outside the aircraft.

Two methods of supplying this high-pressure air are at present employed:

(1) Tapping the compressors of jet engines.

(2) Taking in air by means of a supplementary intake and compressing it by means of an engine-driven blower.

The air is then cooled, either by air-to-air heat exchangers, or by expanding it through a braked turbine, or by a combination of both methods. However, at speeds of Mach 1 and over, any air which can be taken in for use in heat exchangers is at such a high temperature as to render it useless, and some other means of cooling must be found. Fuel cooling is a possibility, but its use is unlikely owing to the danger of leakage allowing the cabin air to become contaminated by fumes.

The alternative is to cool the heat exchanger by means of a refrigerating plant carried within the aircraft. This may involve a very considerable weight penalty, and if the refrigerant is badly chosen the danger of contamination by toxic fumes may still persist. It has been suggested that certain rare gases might be used for this purpose. Some means of maintaining reasonable humidity in the cabin is also required, and this may imply the aircraft carrying a large volume of water.

In aircraft having a lower degree of pressurization and a short flight duration, all the air may be supplied from high-pressure storage bottles carried within the aircraft, and allowed to leak from the cabin at a controlled rate. The pilot would be supplied with oxygen in the usual way, and the saving in weight and space over a full system may be considerable.

Pressurization Failure

At all altitudes, sudden failure of the pressurization system presents an unpleasant and hazardous possibility. As operating heights extend above 50,000 feet, some protection for the crew is imperative: death would very quickly follow any sudden failure.

To overcome this, work is proceeding on the development of "pressure suits," somewhat resembling lightweight diving dress in appearance. Such a suit may be employed in three ways:

(1) The suit only may be pressurized, saving weight and space of pressurization equipment at the expense of safety.

(2) The cabin may be normally pressurized, the suit being inflated by emergency air bottles in the event of the cabin pressure falling below a certain level. This is obviously preferable to (1).

(3) A compromise between (1) and (2), the cabin being pressurized to a reduced differential, thus allowing savings on structure and equipment while retaining a fair measure of safety.

Visibility

The use of long, slender fuselages having a low rate of taper may place the pilot well back from the nose. Combined with the need for keeping the cockpit hood as small as possible to minimize drag, this may mean that when the pilot is approaching the runway for a landing he is unable to see straight ahead, owing to the tail-down attitude of the aircraft. This difficulty may be overcome by "drooping" the nose.

In some cases, for example, tail-first aircraft, such a solution may be aerodynamically unacceptable because of changes in the stability characteristics of the aircraft. This, together with the poor mechanical properties of glass at elevated temperatures, has led designers to consider enclosing the crew completely, presenting a view of the outside world to the pilot by means of a screen within the cockpit. This may be achieved either by direct optical means or by a remote television camera.

Such a system has been tested in mock-up form in the United States. Presumably development along these or similar lines is continuing: the psychological effect of such total enclosure on the pilot seems to be somewhat uncertain at present.

Escape Facilities

An important feature of any high-speed aircraft is the provision of means whereby the pilot can evacuate the aircraft in an emergency. The normal low-speed methods cannot be used, since the crew member is unable to overcome the air loads tending to keep him in the cockpit.

The current solution is the ejection seat, in which the crew member's seat is thrown clear of the aircraft by a cordite charge. The British "Martin-Baker" seats eject upwards and the accelerations involved are considerable, as a high ejection velocity is needed to clear the fin of the aircraft. In the United States a downward ejection seat has been developed, presumably to avoid this, although the use of such a device at low altitudes seems to be somewhat restricted.

The ejection seat, although now a safe and reliable device, is open to certain objections, chief of which are:

(1) At high speeds and low altitudes, the pilot may have insufficient protection from the air blast, and the use of the seat under these conditions is not really practicable.

(2) At high altitudes some means of pressurizing the pilot is required.

To overcome these difficulties it has been proposed that the pilot and his cockpit should be "ejected" together as a pressurized capsule, descending on a common parachute until a safe height is reached at which the pilot can take to his own parachute. Some schemes have been proposed in which the pilot would ride the capsule right down to the ground, but the engineering difficulties of such a method are clearly considerable.

CONCLUSION

Such, then, are some of the problems facing the aeronautical engineer—and some of the reasons why the newer aircraft are costly and take a long time to develop. High-speed, high-altitude flight holds many other snags, but the examples quoted are probably the major, and most pressing, ones. The inescapable conclusion is that future aircraft will be larger, heavier and more complex than present-day ones, and since complexity begets further complexity, the trend seems likely to continue.

A striking development in fire extinguishing agents for petroleum fires has been developed by chemists at the Naval Research Laboratory. Named "Purple K Powder", the agent is finely powdered potassium bicarbonate. It produces dense flame-shielding, fire-quenching clouds which reduce drastically the amount of heat emitted by the fire, allowing fire-fighters to move in for more effective performance. It is non-toxic, inexpensive and can be used with conventional fire-extinguishers. It will soon be available as a commercial product.

—from NAVAL RESEARCH REVIEWS June, 1959

LIEUTENANT (j.g.) JOHN C. COOPER, U. S. NAVY and
CAPTAIN NORBERT FRANKENBERGER, U. S. NAVY

THERMOELECTRICITY— A RAY FROM THE BRIGHTER TOMORROW

THE AUTHORS

***Captain Frankenberger** was graduated from U.S. Naval Academy June 1940. After three years at sea in an aircraft carrier went to MIT where Masters Degree in Naval Architecture and Marine Engineering was awarded in 1945. There followed duty at the Norfolk Naval Shipyard, aboard the carrier CORAL SEA, at Pearl Harbor Naval Shipyard, the Naval Academy, on the Staff of Commander Service Forces, Atlantic Fleet and finally in 1956 at the Bureau of Ships. Duties in BUSHIPS have been first: Asst. Head Machinery Design Branch and presently Asst. Head Electronics/Electrical Design Branch. Has been project officer for BUSHIPS Thermoelectric program since its inception.*

Lt. Cooper was born in Washington March 18, 1935. Attended the University of New Mexico under the "Holloway Plan," receiving his commission and B.S. in Mechanical Engineering in June 1957. Since that time has been assigned to the Bureau of Ships as a project officer, first with the Machinery Design Branch and presently with the Electronics/Electrical Design Branch. Has been connected with the Bureau of Ships Thermoelectric program since its inception.

False facts are highly injurious to the progress of science, for they often endure long; but false views, if supported by some evidence, do little harm, for everyone takes a salutory pleasure in proving their falseness.

—Charles Darwin, *The Descent of Man*

UNFORTUNATELY, the gifted German scientist who discovered the principle of thermoelectricity expressed his "false views" as "false facts". That they "endured long" is incontestable. For well over a century no use was made of thermoelectricity as a source of power.

It was in 1821 that Thomas Seebeck observed that a magnetic needle deflected when placed near a circuit composed of two dissimilar metals whose junctions were at different temperatures. With our present knowledge we could have told Seebeck that what caused the needle's motion was an electric current flowing through his circuit. In fact, just the year before, in 1820, Oersted had demonstrated that an electric current in a conductor is surrounded by a magnetic field which deflects a magnetic needle. Seebeck, however, arrived at a different set of facts. He concluded that he had created a magnet by the

temperature difference between the junctions of his dissimilar materials.

"This explains the earth's magnetic poles" was his announcement. He reasoned that the earth was composed of many dissimilar materials; the poles were cold and the equator was hot; therefore, the magnetism of our planet was caused by the temperature difference.

Although none of his colleagues agreed with him, Seebeck spent the remaining ten years of his life attempting to prove conclusively his false facts. What he actually accomplished was to discourage any development of the generation of electricity directly from heat with no moving parts. What was developed instead was Oersted's electromagnetic discovery which led to the electric generator and motor so commonplace, so efficient, and so taken for granted today. Imagine what over one hundred years of development effort would have produced in the way of thermoelectric power generation!

It seems hardly possible that a similar set of circumstances would plague the discovery of the reverse of the Seebeck effect, but such was the case. Thirteen unlucky years after Seebeck made his discovery, a French watchmaker, Jean Peltier, found that when an electric current passed through a circuit composed of two dissimilar metals, the junctions of the metals would be cooler or warmer than they should have been because of resistance alone. If only he had realized that he had discovered the perfect heat pump—a method of static cooling!

Instead he attributed the effect to a non-applicability of Ohm's law when the electric current was low. Once again, an important discovery was laid aside, and no further development work on the Peltier effect took place for over a century.

What, then, has revived the interest in the Seebeck and Peltier effects in the 1950's? The answer is two-fold. First, with present knowledge, it appears theoretically possible to develop static electric generators and static heat pumps which would be as efficient as existing rotating or reciprocating units. Second, the present expanded knowledge of materials came from work done on semiconductors which began in 1926 and led to the transistor of today. Without the impetus of the semi-conductor program, it is probable that the Seebeck effect would still be used only for temperature measurement and the Peltier effect not at all.

Let us examine, now, the principle of thermoelectricity. Why are we able to get electricity directly from heat? As yet the theory has not been rigorously defined, but the following simplified version serves to explain the results.

Taking metals first and referring to Figure 1, we have a metal being heated at one end. Because of the added energy furnished by the heat to the electrons of the metal, the electrons (represented by the minus signs) move away from the hot end. They congregate at the cool end, thus giving that end a negative charge. A voltage difference now exists between the cool end with its added electrons and the hot end which has lost electrons. All metals behave in this manner, but the number of electrons moved to the cool end by a given amount of heat, and hence the voltage developed, vary with different metals.

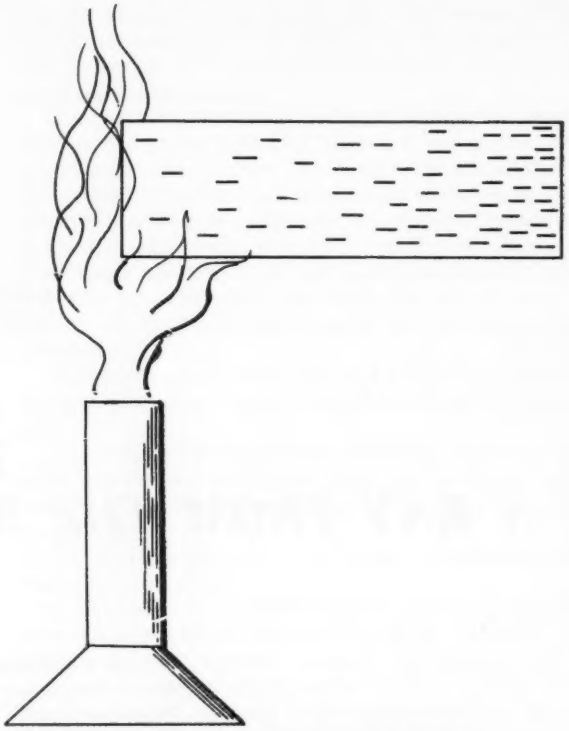


Figure 1. The Seebeck Effect in Metals.
When one end of a metal bar is at a higher temperature than the other, the electrons tend to concentrate at the cool end, hence a voltage exists between the ends.

Figure 2 shows two metals joined at the bottom and receiving heat. The metal on the right has more electrons displaced than the metal on the left, hence its voltage is higher. When the two metals are joined at the top through the circuit shown, a current will flow in a counter clockwise direction. This is not a very good way to produce power, for the voltages of the two metals are opposing each other, and the output is the result of their potential differences. Figure 2 is actually what we have called a thermocouple; it has been used for years in measuring temperatures. The current that flows varies with the heat supplied, and hence the device can be calibrated to read temperature directly. If the voltages in the two legs reinforced instead of opposing each other, the power-producing efficiency would be immediately improved. The semiconductor permits us to do just this.

Semiconductors are so named because their conductivity is between that of the good conductors, the metals, and the poor conductors, the insulators. Where the resistance of metals increases with an in-

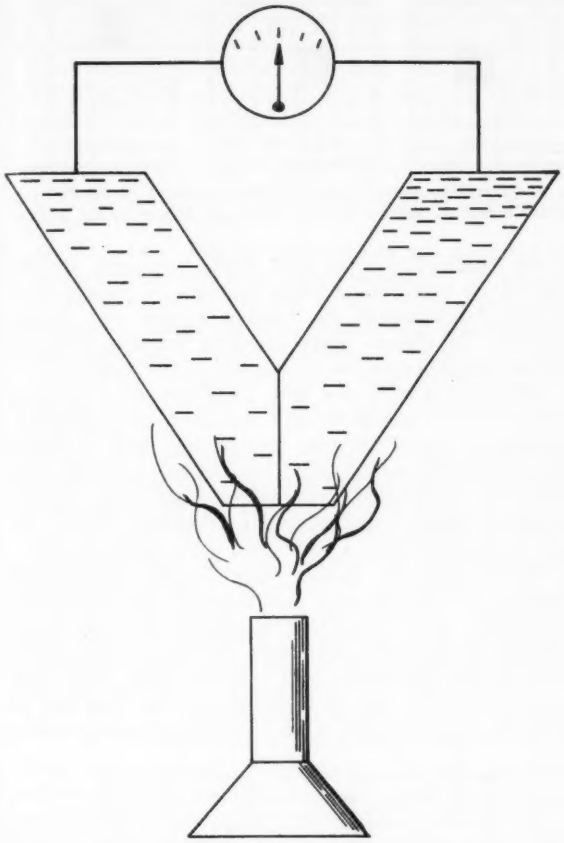


Figure 2. The Bi-Metal Thermocouple.

Two different metals receive heat at one junction and develop opposing voltages. One metal, however, characteristically develops a weaker voltage than the other. The difference then is available for use.

crease in temperature, that of semiconductors decreases. What helps in thermoelectricity, however, is that semiconductors can conduct electricity by electrons and also by the absence of electrons or "holes".

Conduction by electrons in semiconductors could be as shown in Figure 1 for metals. Figure 3 is another way of depicting this action. The railroad tracks of Figure 3 represent the semiconductor, and the cars, the electrons. With the bumper at one end and the bridge up at the other, the electrons cannot move freely nor very far on their own track. When heat energy is applied at one end as shown by the switch engine in Figure 3, the first electron can be humped over to the clear track where it will come to rest at the far end. Similarly if more energy is applied, additional electrons can be pushed onto the clear track to the far end. These figures actually illustrate the energy band theory. The original track is the so-called valence band which, in semiconductors, is filled with electrons at zero temperature permitting no electron movement. When heat is applied, sufficient energy is given some of the electrons to enable them to jump to the empty so-called conduction band where they are free to move away from the source of heat. Less energy is required to make these electrons jump the band gap in semiconductors than in metals, hence without doing anything further we already have a better electricity producing device than with metals. We can further improve on the performance of the semiconductors by adding, in effect, more electrons. This is done by introducing minute quantities of a substance which has one more valence electron than the original semiconductor. The spare electrons so introduced are held much more loosely in the valence bond than the electrons of the base material.

It is as though an extra car was put on the track of Figure 3, with the front wheels already on the downhill side of the switch. Only a small shove from the switch engine is required to start this car rolling toward the bumper at the far end. Similarly, very little heat is required to send the spare valence electron toward the cool end of the "doped" semiconductor. Semiconductors which conduct electricity by electrons, as just described, are called n-type materials since they conduct by negative charges.

As might be expected, the other type of semiconductor conducts with positive charges and is called p-type. These positive charges are really "electrons that are missing". In doping p-type semiconductors, a substance is introduced which has one less valence electron than the base material. This missing electron is called a "hole". When heat is applied to one end of a p-type semiconductor, the holes (the absence of electrons) move away from the heat toward the cooler end. One method of visualizing this

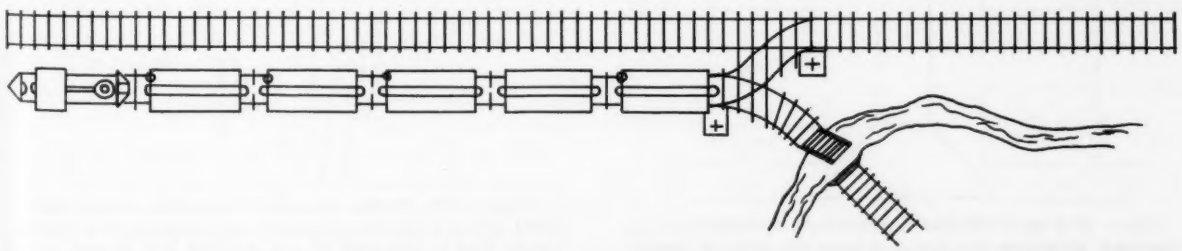


Figure 3. Electrical conduction in semiconductors is analogous to the railroad scene depicted above. See text.

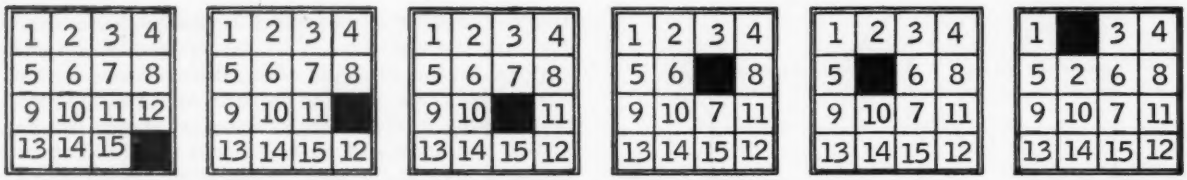


Figure 4. Hole conduction in a p-type material is illustrated by the familiar number puzzle. The electrons move from a filled space to a hole, in effect causing the hole to move in the opposite direction, just as do the numbered blocks in the puzzle.

is shown in Figure 4 which is the familiar number puzzle. At the start, the hole (the missing block) is at the lower right of the puzzle. This hole can be moved to the successive positions shown, by shifting the other blocks. Similarly, in the p-type semiconductor, as the holes (the missing electrons) move away from a source of heat, the electrons in the material move toward the heat source.

We have now two materials which, when joined together, will reinforce each other rather than oppose as the metals did. Figure 5 shows such a couple made up of one p-type and one n-type semiconductor. Each leg of the couple now contributes to the power output and the efficiency of power generation rises to 1 to 2 per cent. Higher voltages are obtained by connecting more couples in series, each couple contributing its voltage to the overall potential. To obtain more current, several rows of series couples may be connected in parallel.

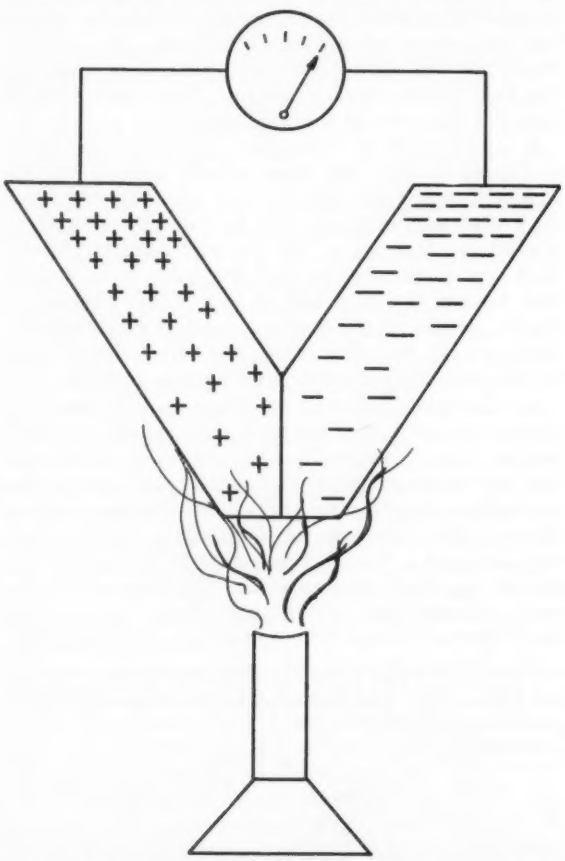


Figure 5. A more efficient thermocouple is formed of a p-type and an n-type leg joined so that the voltages compliment each other.

Efficiencies of 1 per cent or 2 per cent are not values which would prompt anyone to view thermoelectricity as a serious competitor with rotating steam-electric generators. These values have already been far surpassed, but before discussing today's status of power generation (the Seebeck effect), let us examine how and why the Peltier effect works.

Recall that the Peltier effect is the cooling and heating of the opposite junctions of two dissimilar materials when a current is passed through them. This is fairly easily explained for the n- and p-type semiconductors when you consider how they conduct electricity, the n-type by electron and the p-type by holes. Figure 6 shows a simple p-n junction

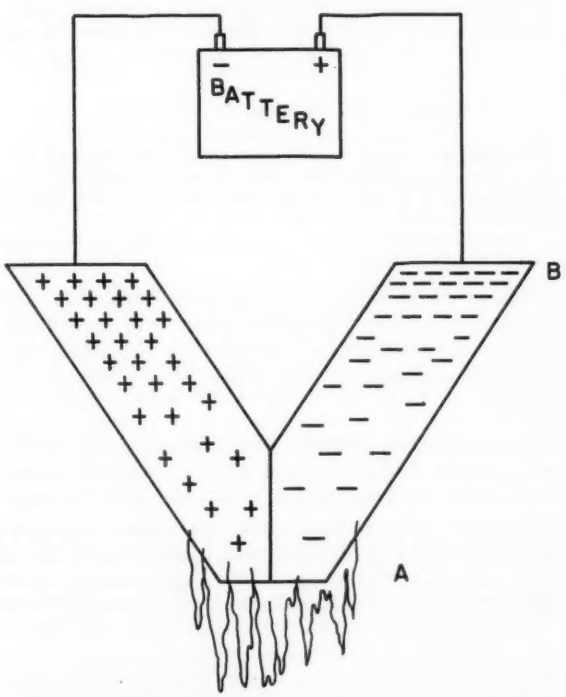


Figure 6. The Peltier effect is the converse of the Seebeck effect. When a current is caused to flow through a thermocouple heat is absorbed at one junction and carried to the other. Thus one junction is cooled, the other is heated.

with a voltage impressed. In the n-type, the electrons are flowing away from the end marked A; hence, energy is leaving this end and it becomes cool. The electrons concentrate at the end marked B and this end, where energy has been transferred, becomes warm. In the p-type, the holes, or positive charges, similarly flow away from the A end, cooling it, while their concentration at the B end makes this end become warm.

In a metallic couple, such as the one depicted in Figure 2, both legs conduct by electrons. However, the freedom of movement of electrons differs for each metal. The one whose electrons are freer to move will become cooler at end A than the other metal. If the difference in their electron freedom is sufficient, the A end will be noticeably cooler than the B end.

Because thermoelectric power generation is in its infancy in this country, there is as yet no accepted terminology. Technical societies are at work, however, to establish a set of definitions which, on adoption, will eliminate some of the difficulties in precisely expressing thermoelectric properties. One of the properties which must be carefully defined to avoid misunderstanding is thermoelectric efficiency. This term means different things to different people. Perhaps the strictest definition is: Efficiency =

$$\frac{\text{Useful power output}}{\text{Heating value of fuel at rate of use}}$$

Using this equation and present materials and conventional fuels, an efficiency of about 8 per cent could be realized in a thermoelectric generator. Another value of efficiency frequently used is: Efficiency =

$$\frac{\text{Power output}}{\text{Rate of heat delivered to thermo elements}}$$

With this equation, higher values of efficiency result because the effectiveness of heat transfer, the stack or chimney losses, and any power required for auxiliaries is ignored. Efficiencies of about 12 per cent can be calculated using this equation.

Other more complicated theoretical equations are also in common usage. These always include temperatures, specific material properties and, at times, the geometry of the materials. Basically, however, they all are some form of the expression:

Efficiency = Figure of Merit × Carnot Cycle Efficiency.

Carnot Efficiency is the maximum that can be realized in any device that receives heat at one temperature and rejects heat at a lower temperature. The equation is:

$$\text{Efficiency}_{\text{Carnot}} = \frac{T_{\text{Hot}} - T_{\text{Cold}}}{T_{\text{Hot}}}$$

where the temperatures (T) are in degrees, absolute. This equation suggests immediately one method of increasing thermoelectric efficiency—simply increase the temperature at which heat is received. This is indeed an ideal procedure except that some thermoelectric materials have a frustrating property of melting or losing their thermoelectric properties when their temperatures go too high. Similar difficulties occur on the cold side in that the thermoelectric properties degrade rapidly below certain well defined temperatures. The result of this behavior is that for each thermoelectric material, there is a certain temperature range for which it produces electricity most efficiently. If temperatures outside this range are used, the degradation in properties exceeds the gain in Carnot efficiency. A net loss in efficiency results. Luckily both p- and n-type thermoelectric materials have been developed which, each in its best temperature range, cover the temperatures from about 32°F to 2000°F with creditable efficiencies. The trick, then, is to join or cascade these different materials into a single unit so that each operates within temperatures giving it the highest efficiency. Figure 7 schematically shows such an arrangement with typical materials listed in their preferred temperature zones.

The figure of merit, mentioned previously, is a measure of how well thermoelectric materials will function. It is defined as:

$$Z = \frac{E^2}{\rho K}$$

where:

Z = figure of merit in $°C^{-1}$
E = Seebeck coefficient in microvolts/°C
ρ = Electrical resistivity in ohm-centimeters
K = Thermal conductivity in watts/centimeter °C

This is another thermoelectric property which needs better definition. All the terms involved are definitely temperature dependent, yet temperature is not in the equation. The units of Z itself—"per de-

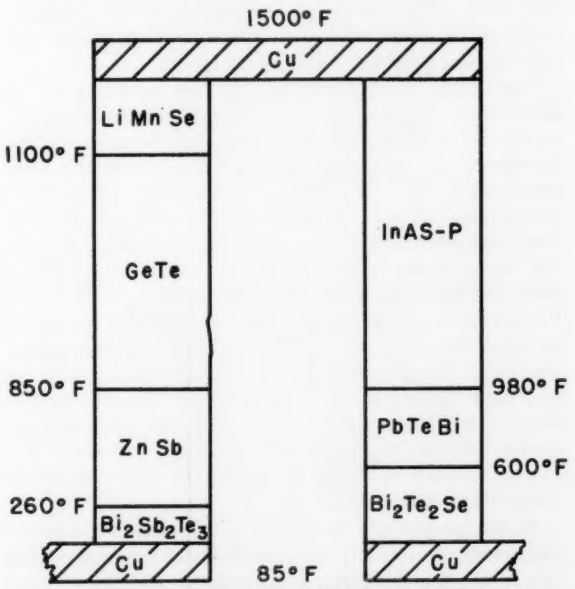


Figure 7. A "Sandwiched" Thermocouple.

Each leg is made up of two or more materials, each operating over its best temperature range. Typical materials and temperatures are shown.

gree centigrade"—are rather awkward and evade visualization. Nevertheless, Z does allow comparison of different materials provided the temperatures at which the factors are measured are known. The higher the value of Z, the better the material is.

An examination of the equation for Z reveals what makes a good thermoelectric material. The higher the volts produced per degree centigrade temperature difference, the better the material. Since the term E is squared, it would seem that this would be the best property to attack to improve performance. However, in the perverse manner of nature, when a material with a high E is found, it invariably has also such a high value of thermal conductivity or electrical resistivity, or both, that the advantage of high microvolts per degree is nullified.

The internal resistance ρ must be small, otherwise most of the power produced will be used in overcoming this resistance and little will be left for useful external application.

K also should be a low value since power production depends on keeping the opposite ends of the thermoelectric couple at different temperatures. If the thermal conductivity is too good, the temperatures at both ends will tend to equalize and the power will fall off.

APPLICATIONS

The coming widespread exploitation of the Seebeck and Peltier effects will bring many new innovations into the home and laboratory as well as to the armed services. Marked increases in materials capabilities have been achieved in the past two years, and when the improvements now forecast for the next two years are indeed achieved, present methods of pumping heat and generating power will have a new and serious competitor.

For many years thermoelectricity was applied to advantage only in the field of temperature measurement. To measure temperature, one junction of the thermocouple is placed where it will attain the temperature to be measured, and the other junction is maintained at some reference temperature, usually room temperature or that of melting ice. By measuring the voltage developed by the couple, the difference between the reference and unknown temperatures can be easily established. These devices can be as accurate as their voltage measuring equipment and lend themselves readily to remote monitoring and high temperature measurement. Thermocouples will probably continue to be used for temperature measurement for many years to come, but their real future lies not in this area, but in the fields of power generation and heat pumping.

A list of patents concerning the uses of thermoelectricity can cover the range from battery chargers to electric bicycles, from minute coolers of electronic components to large refrigerators and air conditioners; but the thermocouple has found very little practical application as a power converter or heat pump in the past. The attainable efficiencies were simply too poor to make devices attractive, or in many cases, even to make them possible.

During World War II several experimental generators were built for the United States Army. These devices burned gasoline and were capable of delivering from five to twenty watts of electricity. Their conversion efficiency was about 1 per cent. By contrast, small generator sets driven by gasoline engines can be about 20 per cent efficient, and large power plants approach a thermal efficiency of 40 per cent. These preliminary thermoelectric units soon went the way of many other experimental devices, appearing as oddities in physics demonstrations and finally disappearing entirely.

With the recent advent of semiconductors the first spark of this ray from the brighter tomorrow appeared. It became possible to build practical units for several unique applications. In Russia a small generator has been on the market for several years. The generator converts some of the heat from a kerosene lamp to electricity which in turn operates a radio. Other generators with outputs up to 1000 watts and a number of refrigeration devices are also said to have been produced.

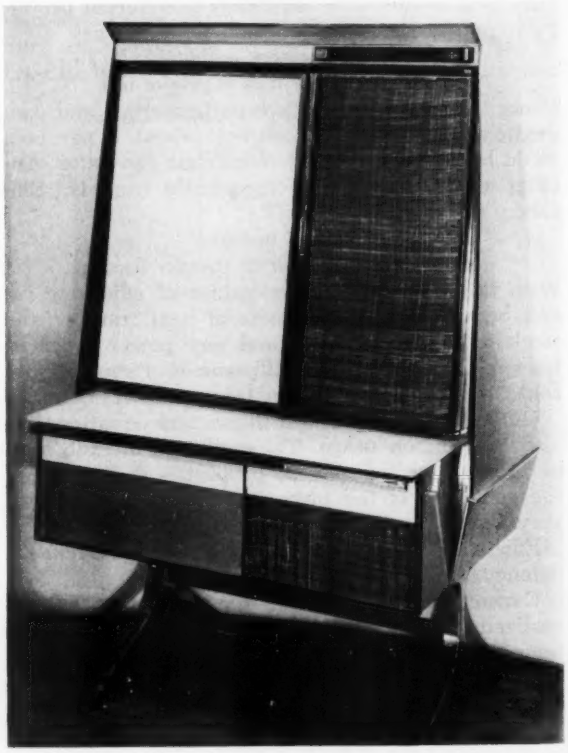


Figure 8. A 3.5 cubic foot thermoelectric refrigerator has no moving parts in the refrigeration unit. A device of this type is now feasible, but would require about twice the power of a normal household refrigerator. Predicted materials improvements should make thermoelectric refrigeration competitive in the commercial market in the next few years. Photo courtesy Westinghouse Electric Company.

Recently in America a number of futuristic devices have been shown: a refrigerator with 2.3 cubic feet capacity, a slightly larger, very modernistic one enclosing 3.5 cubic feet (Figure 8), a generator capable of producing 8 watts of electricity, and another, shown in Figure 9, with an output of 100 watts. The direct current output of these generators is converted to alternating current by transistorized inverters.

Figure 9. 100 watt thermoelectric generator burns propane, is air cooled, and converts heat to electricity at an efficiency of about 8 per cent. Photo courtesy U. S. Air Force.

These units all operate without moving parts and can perform well the tasks for which they were designed. However, they are mainly exercises in extensive research projects and are not ready to compete commercially with other more firmly intrenched methods of performing the same functions.

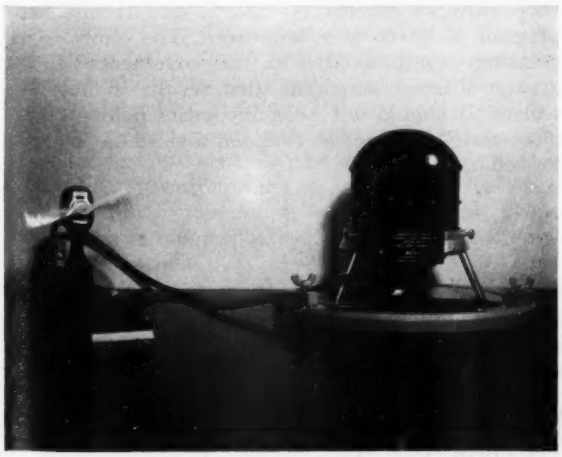


Figure 10. Radioisotope fueled thermoelectric generator weighing five pounds has an integrated power output equivalent to 1450 pounds of nickel-cadmium batteries. The long life and reliability of the thermocouples make such a power source possible. Photo courtesy of Atomic Energy Commission.

Thermoelectric devices can today perform some tasks better than any other method. Generators such as the one shown in Figure 10 can deliver several watts of power for months or years, supplanting

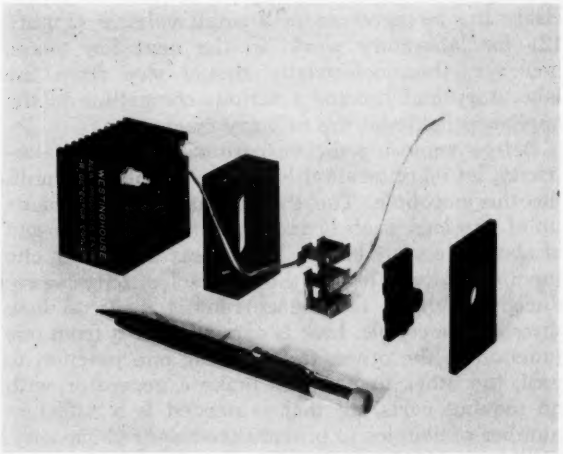


Figure 11. Exploded view of an infra-red detector cooler. The thermocouples are in the center. Heat is absorbed through the pedestal of the aluminum heat collector on the right and rejected from the finned section at left. Photo courtesy Westinghouse Electric Company.

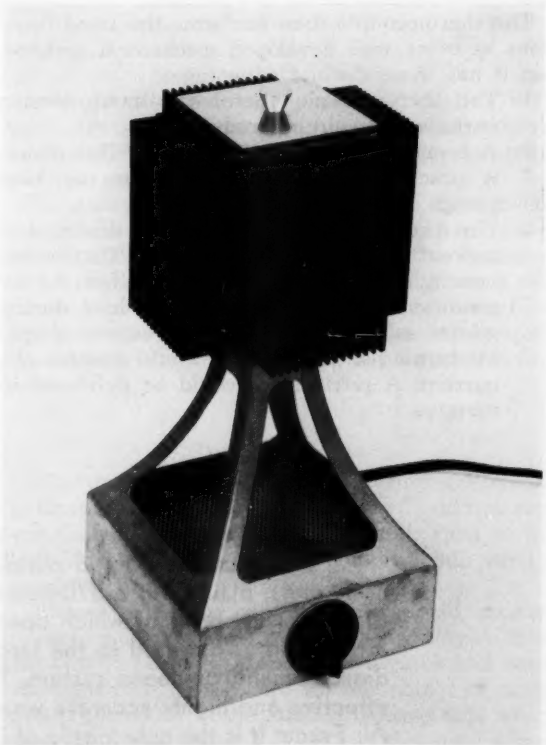


Figure 12. A controlled temperature chamber for laboratory use. The internal volume can be maintained either above or below ambient temperature. Photo courtesy Westinghouse Electric Company.

thousands of batteries. A minute cooling device like the one shown disassembled in Figure 11 can cool the detector of an infra-red receiver and greatly improve its sensitivity. With thermoelectric cooling-heating, it is relatively easy to control very precisely the temperature of a small volume (Figure 12) for laboratory work. In the next few years, however, thermoelectricity should step from the laboratory and become a serious competitor in the appliance field and the military market.

Before exploring the vast future for thermoelectricity, let us reiterate the abilities of the basic unit, the thermocouple. The thermocouple can be made up of two legs, each ¼ inch or less in diameter and of about the same length. When heat flows from one junction of these legs to the other, electricity is produced; when an electric current is made to flow through the couple, heat is carried with it from one junction to the other, thus causing one junction to cool, the other to heat. To make a generator with no moving parts, all that is needed is a sufficient number of couples to provide the required capacity. Heat is supplied to one end of the couples; the other end is cooled. To make a refrigerator or air conditioner (heat pump), one merely reverses the process, supplying the necessary electricity to the couples, allowing it to absorb heat at the cold junction and reject the heat at the hot junction.

The thermocouple then performs the same functions as other well developed mechanical systems, but it has these distinct advantages:

1. The thermocouple operates without moving parts to wear out or produce noise.
2. A complete couple is quite small. This makes it practicable to build generators or heat pumps of almost any desired size.
3. The direction of heat flow and the direction of current flow are directly related. That is, reversing one will also reverse the other. An air conditioner then can be made to heat during winter as well as cool in the summer simply by turning a switch that would reverse the current. A refrigerator could be defrosted in minutes.

Today's thermocouple can convert up to 10 per cent of the heat it receives to electricity, while our best power plants approach 40 per cent efficiency. Presently, refrigeration by this means would require two to three times the power needed by a good mechanical system. These mechanical systems can be, however, very large and complex, and efficiencies decrease rapidly as they are simplified and reduced in size and cost. This makes thermoelectric devices practical today for some applications. It is confidently predicted that within two years the performance of the thermocouple will be twice what it is today. When this prediction becomes a fact, the household refrigerator can be economically replaced by several smaller, portable units which could be built into cabinets or moved around as desired. An electric ice bucket could be as attractive and portable as a toaster. Radiant heating-cooling panels could be built into the walls or ceiling of a house for year-around air conditioning.

A thermoelectric generator with 20 per cent efficiency, combined with a good storage battery, might make the electric-drive automobile again a competitor in the field of transportation. Small self-contained generators for use in boats or trailers will be quiet and trouble-free. The present generators in airplanes and automobiles could be replaced by generators using heat that is otherwise wasted, rather than part of the mechanical power needed to drive the vehicle.

The possibilities for the future use of thermoelectricity are almost boundless. The key to this future is research in the field of thermoelectric materials and the development of techniques for their application. The Armed Services and industry are together supporting an extensive research and development program to meet this basic need. The effort is increasing continuously as improvements foster greater interest which in turn results in new advances. It should not be many years before "thermoelectric" becomes as common a word as "transistorized".

An air-to-surface guided missile has become operational in fleet aircraft units. BULLPUP, a 570-pound weapon is carried by A4D and FJ-4 type aircraft, both of which operate from aircraft carriers. The missile, after firing, is directed to the target by the aircraft pilot by a simple radio command guidance system. Tests have proven the missile to be an effective and highly accurate weapon. BULLPUP also will be used by the Air Force. It is the only missile of its type now operational.

—Defense Department News Release

"ENGINEERING"

WHERE TRANSISTORS STAND TODAY

ACKNOWLEDGEMENT
This staff article appeared in the June 5, 1959 issue of "Engineering."

"AN AMAZINGLY SIMPLE DEVICE, capable of performing efficiently nearly all the functions of a thermionic vacuum tube. . . . Known as the transistor, the device works on an entirely new physical principle discovered by the Laboratories in the course of fundamental research into the electrical properties of solids." This is an extract from the news release given by the Bell Telephone Laboratories, where the transistor was invented, almost 11 years ago.

Since then, in a little more than one decade, this small device has grown from little more than a scientific curiosity into a whole new industry—one that is adding significantly to the progress of electrical engineering and, by so doing, is becoming the prime mover of a number of advances in the field of engineering as a whole.

The progress of these devices has occurred so rapidly in recent years, and in so many different places, that the problem has arisen of exchanging information on an international basis. For this reason, the Institution of Electrical Engineers promoted the International Convention of Transistors and Associated Semiconductor Devices and the International Transistor Exhibition, both of which were held at Earls Court, London, from 21 to 27 May. The convention brought together some 1,850 international delegates, including the Nobel Prize winning inventors of the transistor, Professor J. Bardeen, Dr. W. M. Brattain and Dr. W. B. Shockley. Some 150 papers and lectures were presented, dealing with recent developments in basic theory, measurements of characteristics, applications and manufacturing techniques.

The success of these combined events, the convention and the exhibition, might be said to have formed a milestone in the development of a new industry; one which has marked its maturity and given it official status as an engineering entity. At the same time they have sparked off a renewed and more vigorous general interest in the technology of semiconducting devices.

THE TRANSISTOR

In his opening address at the Convention, Viscount Hailsham is said to have remarked: "I do not suppose that one person in ten thousand, even in the most industrialized countries, could explain what a transistor is, or even a semiconductor."

"Eleven years ago no one could have said, because transistors did not exist. Yet they now play an integral part in our lives, from the satellites and space vehicles which revolve around our planet or probe toward the moon to the humble hearing aids which assist the deaf towards a fuller and therefore a happier life. For the transistor is, I am confidently assured, the most significant development in electronics since the invention in 1904 of the thermionic valve."

It was certainly not an overstatement to rank the

invention of the transistor with that of the vacuum valve. It is also probably true that few people (engineers included) could ably explain what a transistor is; after all, one decade is not much in terms of engineering history and the transistor is only one of many hundreds of engineering developments that have occurred during that time.

However, the transistor has now shown itself to be one of those rare devices which, like the vacuum valve, will have far reaching effects on many branches of engineering other than that from which it was evolved. For this reason, this article has been written as a general and simplified introduction to the principles of the transistor, a summary of its present-day applications and a guide to the possible applications of the future.

Briefly, the transistor is an electronic device which makes use of the physical properties of semiconducting materials to form a circuit element having the ability to oscillate and amplify small electrical signals. But what are semiconducting materials? Well, to begin with, they are materials which have electrical conductivities ranging between those of metals and insulators. That is to say, they are semiconductors of electrical current. The most important of these materials, as far as transistors are concerned, are germanium and silicon, both of which are from group IV of the periodic table. Germanium has been the most widely used so far, although the thermal properties of silicon have led to an increase in its use since germanium tends to become a conductor at relatively low temperatures, thus restricting its range of applications.

The germanium atom has four electrons in its outer shell, that is, four valence electrons. In a pure crystal of germanium these electrons link up with those of neighboring atoms to form what is known as a covalent bond (see Figure 1). This makes the crystal a perfect insulator, since there is no tendency for electrons to be induced into or out of the material. However, if small traces of a suitable impurity are present, having either more or less than four valence electrons, the perfect bond no longer exists throughout the crystal structure, and there will either be some free electrons or a deficiency of electrons, either of which will allow a limited current to flow. Thus, by introducing the right type of impurity, e.g. indium (three valence electrons) which leaves an electron deficiency in the crystal, or arsenic (five valance electrons) giving an electron surplus, two types of semiconducting material may be produced (see Figures 2 and 3). The former type (electron deficient) is known as a "p-type," because it is considered as a positive "hole" carrier and the latter type is known as "n-type," because it has negative carriers (free electrons).

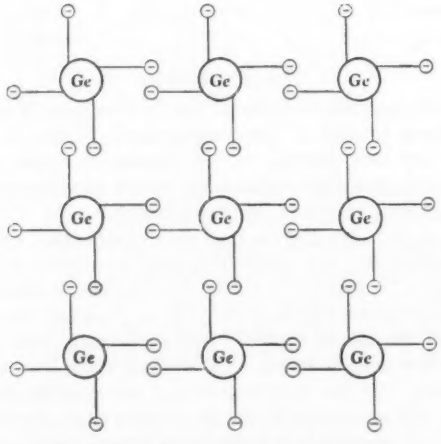


Figure 1. Structure of pure germanium crystal.

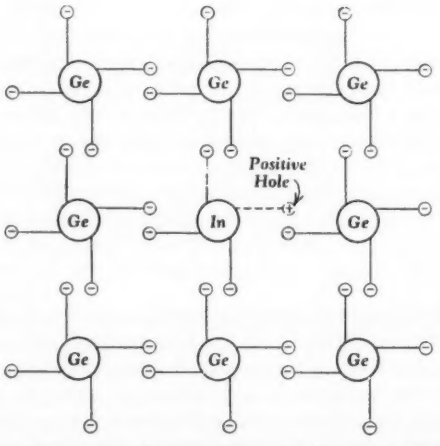


Figure 2. Structure of germanium crystal with indium impurity added—showing how a "positive hole" is formed.

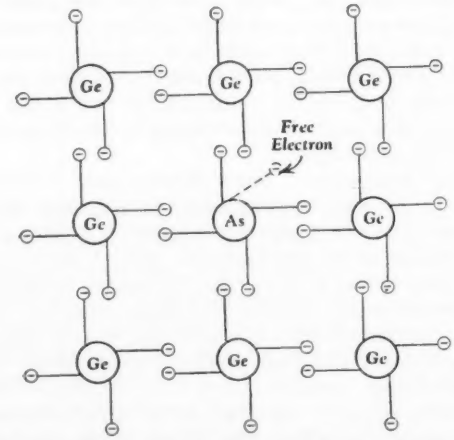


Figure 3. Structure of germanium crystal with arsenic impurity added—showing how free electron is formed.

The conducting action of an n-type semiconductor, under the influence of an electric field, is much the same as that of a metal, but with higher resistance to flow. However, the action of the p-type is more subtle. The usual way to describe this action (although it is not strictly correct) is to say that electrons "jump" into the vacancies (holes) of the impurity atoms, always going in the direction of the positive force, resulting in a migration of positive holes toward the negative force (see Figure 4). If

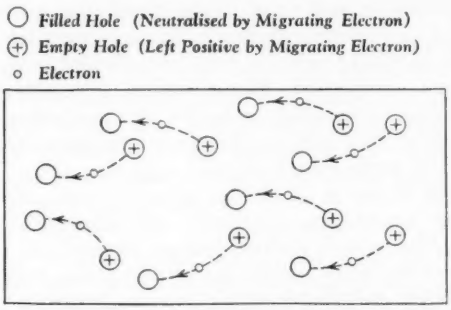


Figure 4. Electrons migrate in one direction—effectively producing a "positive hole" migration in the opposite direction.

an n-type material is formed into a junction with a p-type, an electric field is formed at the boundary —this is the phenomenon which enables these materials to act as amplifying devices. The direction of this field, known as the barrier field, tends to inhibit the flow of both electrons and holes across the junction. However, if a voltage is applied to this junction so as to oppose this field, current flow may take place. A simple junction of this type may be used to rectify alternating current, since the voltage in one direction will overcome the barrier and allow current to flow, while the voltage in the other direction will add to the barrier field and inhibit current flow still more.

The transistor goes one stage further than the simple two stage junction rectifier. A thin layer of p-type material is sandwiched between two thicker layers of n-type material to form what is known as an n-p-n junction transistor (p-n-p types also exist and are fundamentally the same). The central layer is called the base and is analogous to the grid of a vacuum valve. The material on the input side is called the emitter (similar to the cathode of the vacuum valve) and the material on the output side is called the collector (like the anode of the vacuum valve).

These three "electrodes" may be connected as shown in Figure 5, the emitter being biased to overcome its barrier field and the collector being biased to assist its barrier field. These voltage connections allow the emitter to pass electrons into the base but prevent the collector from doing the same. However, the collector, which is positive, will attract any elec-

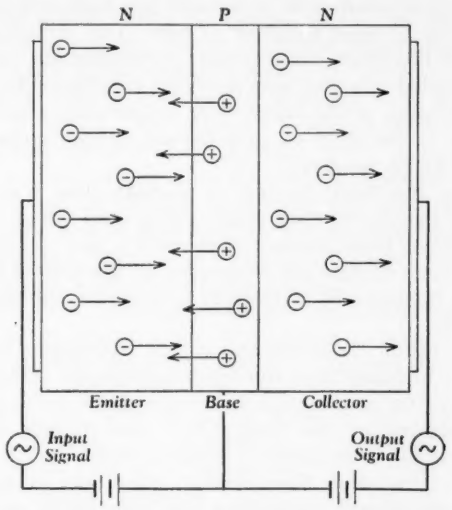


Figure 5. Connection of n-p-n junction transistor. Fluctuations of the input signal produce identical fluctuations in the output circuit with an amplification of power.

trons which enter the base from the emitter, thus allowing a current to flow into the output circuit. If the signal current varies, so will the collector current, thereby producing an action similar to that of a thermionic valve. The current in the collector may only be the same as that in the emitter, but due to the high impedance of the collector junction, greater output energy may be handled there, resulting in power amplification.

Thus we have an analogy between the vacuum valve and the transistor in that the transistor can effectively enlarge small electrical signals. Although the junction transistor described here is the most widely used at present, it is rapidly being superseded by ones produced by new techniques of construction, particularly alloy diffusion.

ITS APPLICATIONS

An analogy between the valve and the transistor can be drawn to illustrate what the transistor can do, but beyond that the similarities end. Not only are the physical principles different but there are many relative advantages and disadvantages, the balance of favor tending to fall more on the side of the transistor as its development progresses. The main advantages of the transistor are its size (many times smaller than an equivalent valve), its low power requirements, its low voltage requirements, its low heat output and its mechanical ruggedness.

These combined features have made it possible to reduce the size and weight, and increase the reliability, of many types of electronic equipment to a remarkable degree. During the past five years a great deal of communications, navigation and con-

trol equipment used in aircraft has been reduced in size by at least a factor of five. The reduction in space has been even greater in equipment for use in guided missiles and artificial satellites. Further reductions, of the order of 10 to 100 times seem possible in the light of new circuit concepts that are now being evolved.

For the flight testing of aircraft, new transistorized equipments are today being used which could not have been carried in aircraft a few years ago. One such equipment, developed in the United Kingdom, contains 90 transistors in a unit weighing only 3½ lb.

In radio communications and telephone equipment, in computers, nucleonic equipment, industrial measuring and control apparatus and electro-medical apparatus, the transistor is also finding an increasingly wide range of applications. Portable radiation monitors have already gone over largely to transistors and transistors are now being used in most of the newer designs of digital computer. Computer installations which at present require a large room are likely, in a few years time, to be no larger than an office desk or filing cabinet.

Another field of application which will demand large quantities of transistors and other semi-conductor devices, is the electronic telephone exchange. Transistorized telephone switching systems require less than one quarter of the floor space of the conventional electromechanical systems and the speed of switching can be increased a thousandfold.

As the reliability is improved to the point where transistors give consistent performance for 20 years or more, they will also be in great demand for use in further transoceanic telephone cable installations. By using the newer types of high frequency transistor now being developed, it should be possible to handle hundreds of telephone conversations on a single cable.

SEMICONDUCTOR DIODES

In addition to transistors, during the past 11 years a large range of semiconductor diodes and rectifiers has been developed. These are essentially two terminal devices which have the property of passing current in one direction only, as previously mentioned. They can be broadly divided into signal diodes, microwave mixer and detector diodes, zener or reference diodes and power rectifiers. Germanium point contact diodes, which are low current rectifiers, are extensively used as detectors, interference suppressors and mixers in radio and television receivers. Silicon point contact diodes are mostly used as microwave mixers in radar equipment.

The score of these devices has been greatly extended since the advent of junction formations, which have largely superseded the point contact technique. By forming a junction between two different types of semiconducting materials in a similar manner to the junction transistor, the current carrying limitations of the point contact have been largely overcome. The current carrying capacity of these devices is now of the order of several hundred amperes per square centimeter of junction area, and electrical efficiencies of well over 90 per cent are possible. Germanium devices of this kind are largely used in low voltage high current supplies.

Small junction diodes find extensive use in power packs, and the larger ones are to some extent replacing selenium and copper oxide rectifiers in battery charging and other power rectifying units. By suitably connecting diodes in series or parallel, their power handling capacity may be sufficient to operate traction equipment. Semiconducting rectifiers are becoming increasingly used for electroplating, electrolysis and numerous other industrial processes demanding large direct current supplies.

Zener diode is the name given to semiconductor voltage regulators, stabilizers and reference diodes. They have a well defined voltage breakdown region and are therefore similar in nature to neon and other gas filled stabilizing tubes. Zener diodes are now widely used as reference devices in stabilized transistor supplies and as a coupling element in transistor d.c. amplifiers.

More recent developments in semiconductor diodes include many forms of extra fast switching devices, of particular value in connection with data processing equipment. One of these, the p-n-p-n switching diode (a four element structure with two terminals) is capable of switching speeds in the millimicrosecond region. Another recent development, which has vast potential possibilities in connection with industrial electronic equipment, is a silicon controlled rectifier. This device has similar characteristics to the thyratron.

Parametric amplifiers are yet another significant recent development in the field of semiconductor diodes. These are used as variable capacitors in such a way as to form low noise u.h.f. amplifiers. Compared with other solid state devices such as the maser, parametric amplifiers have the advantage that they do not require a coolant for their operation. Most of the applications of these devices have been in classified Government work, but they will clearly be of considerable use in the future to the development of radar, telemetering, radio astronomy and satellite communication systems.

OTHER SEMICONDUCTOR DEVICES

Although the photosensitive properties of semiconductors have been known for many years, the intensive research, which has followed upon the invention of the transistor, has led to numerous developments in this field. Photo-conductors are now available which are sensitive to radiations extending from the deep ultra violet to the far infrared region. Numerically, the wavelength range of these

devices extends from about 0.3 up to about 10 microns. In the visual photoconductive group, cadmium sulphide cells are now being made which are 20,000 times more sensitive than the conventional emissive type of photocell. Even from a very weak source of light, these new cells will produce enough current to operate a large relay directly.

Among the infra red sensitive cells, types are now available which are able to detect the heat radiation from a soldering iron from a distance of 100 yards. Such devices are extensively used as detectors in guided missile homing systems. Industrially, such cells offer a wide scope in low temperature radiation pyrometers for measuring temperatures from about 150° C upwards. Other cells, particularly of the indium antimonide and lead selenide types, open up new possibilities for spectrometers for analyzing paints, plastics, resins, petroleum products and many other organic compounds.

Silicon photodiodes, or photovoltaic cells as they are often called, are now being used to convert solar radiation into electrical energy. Their main application so far has been to generate power for the electronic instruments in artificial satellites.

The thermoelectric junction effect, on which bimetallic thermocouples are based, is also being exploited in semiconductor engineering. Employing this principle, thermoelectric generators are now being produced in bismuth telluride and other related compounds. Studies in this field are being actively undertaken in several countries: for instance in Russia, radio sets have been manufactured to operate from thermoelectric generators driven from the heat of ordinary paraffin lamps.

In much the same way as it is possible to convert thermal energy into electrical power, so it is possible to remove heat by electrical energy. This effect is being used in a number of prototype semiconductor refrigerators. Elements of this kind have been produced by means of which a temperature of about—60° C can be achieved. The practical applications of semiconductor refrigerators would appear to be quite considerable. They can be made compact, require little power, have no moving parts and expend with the necessity of a cooling liquid. Refrigerators of this kind have already been put to use in the Russian TU-104 airliners.

MANUFACTURE

In manufacturing transistors and other semi-conductor devices one of the most difficult tasks is to produce the basic material, say, germanium with a very low order of impurity. Although each manufacturing organization has its own technique, they are all basically similar. Newmarket Transistors Limited, who are connected with the Pye Group, produce and handle "transistor germanium" on the following lines. After refining natural germanium until it has an impurity content of about one in a hundred million parts or better, small amounts of this germanium are placed in carbon containers together with a controlled quantity of "dope." This so called dope is the desired impurity such as indium or arsenic. The mixture is then heated until it melts, at about 900° C. A small "seed" of germanium is then lowered on to the surface of the molten mixture and, as the cup containing the mixture revolves, the seed is slowly withdrawn and a crystal of the required germanium begins to "grow" on it, shaping into a rod about an inch thick.

During the growing process a resistivity test is carried out to ensure that the correct degree of desired impurity has been obtained. Without this impurity the transistor would not work. When the crystal is correctly doped it is ready for sawing. In this process the germanium is trimmed and mounted on glass in a bed of wax, then sliced with a high speed diamond cutter. The slices are smoothed and etched down to a thickness of about six thousands of an inch. These slices are then cut with an ultrasonic drill to obtain some 50 or 60 tiny wafers of germanium from each slice.

The subsequent handling of these tiny components and others that are even smaller, has lead transistor manufacturers to adopt mass production techniques that are similar to, and in some ways more exacting than, those used in the watchmaking industry. Many of the production techniques that have been evolved are peculiar to semiconductor engineering and have contributed significantly to the overall development of this new industry.

FUTURE TRENDS

Semiconductor engineering and science has been advancing on a broad front for the past few years, and will no doubt continue to do so for some time to come. Developments are continuing in basic theory, materials, circuit techniques and manufacturing methods at an increasing rate. Although many problems are still outstanding, such as temperature and frequency limitation and the cost of production, they are being overcome very rapidly as intensive research continues throughout the world. It can be expected, with some degree of confidence, that the high frequency limit of the diffused germanium transistor will eventually be increased to several thousand Mc/s. It is also believed that there is no fundamental reason why power transistors with collector dissipations approaching one kilowatt should not be achieved.

In addition to the much used germanium and silicon, other materials, known as compound semiconductors, will undoubtedly be used in the future for many of the more special applications. For instance, silicon carbide and indium phosphide, both of which have a high energy gap, may be used for applications involving temperatures up to 500° C. Other compounds, such as indium antimonide and indium

arsenide are being developed for devices which require a high electron mobility, such as photoconductors and Hall-effect devices.

Many potentially useful devices have recently appeared on the horizon, such as the field effect transistor, the space charge limited device, the unipolar analogue transistor, the spacistor and new multi-region devices, each of which will be the subject of intensive development and some of which will doubtless come to fruition. With these and many other developments yet to come it is reasonable to suppose that, within the next decade, semiconducting devices will not only have outstripped thermionic devices in most of their applications but that they will open up entirely new fields in both science and engineering.

The RCA Laboratories have announced the development of a tiny unipolar transistor having direct application as a logic circuit element. Formed of a tiny piece of silicon with a volume of 16 millionths of a cubic inch, it is estimated that 100,000,000 could be crammed into a cubic foot. Present logic circuit elements include various types of tubes, transistors, resistors and condensers. By use of various numbers of the new elements in different arrays, RCA scientists say that all the functions of present conventional logic elements can be performed without the use of any other type of components. Logic circuit elements assembled of the new device could be mounted on small wafers, which can be built into versatile computer elements by proper assembly.

—from JOURNAL OF THE FRANKLIN INSTITUTE
June, 1959

Cooling infra-red detection tubes to extremely low temperatures greatly increases their sensitivity and makes them respond to a wider range of wave-lengths. This increases the distance of detection for a given target. An ingenious miniature refrigerator has been devised by personnel of Authur D. Little, Inc., of Cambridge, Mass. Weighing 8 ounces, the infra-red cooler utilizes 300 psi helium which expands in a quarter inch diameter cylinder, giving it the capacity of refrigerating an infra-red cell to 60° K (minus 350° F). An entire closed cycle system has been developed, using this cooler, which weighs less than 20 pounds and is capable of being airborne. It is hoped that this system may permit the detection of aircraft or missiles at great distances.

—from JOURNAL OF THE FRANKLIN INSTITUTE
August, 1959

J. HARVEY EVANS

BASIC DESIGN CONCEPTS

THE AUTHOR

is Associate Professor of Naval Architecture at the Massachusetts Institute of Technology. A native of Rochester, New York, he received the Bachelor of Engineering Degree from the University of Liverpool, England, in 1937. For ten years he was employed in his profession by the Central Technical Department, Shipbuilding Division of the Bethlehem Steel Company, Quincy, Massachusetts. In 1947 he joined the faculty of M. I. T. as an Assistant Professor and became an Associate Professor in 1952. In 1957 he served as Advisor in Engineering to Seoul National University, Seoul, Korea. He is a former member of the National Research Council Committee on Ship Structural Design and past Chairman of the New England Section, the Society of Naval Architects and Marine Engineers. He is presently a member of the Hull Structure Committee and the Papers Committee of that Society.

GRANTED that the ultimate end to the endeavors of all technology is to improve the lot of mankind, the only significant difference between "engineers" and "scientists" is in the immediacy of their concern for the implementation of this ideal. In their highest manifestations the projection of creativity and the tool of analysis are essential to both views. In education, the birth of wisdom should be sought no less than the development of intellectual brilliance.

Especially in design integration and optimization is the former quality absolutely necessary, and the training of engineers should reflect this emphasis, for design is surely one of the prime facets they must cope with thereafter in their professional lives.

H. L. Cox is quoted as saying that, "Design is, after all, an art, and the art of design may be defined as the attempt to achieve a precise object only vaguely known, by the application of strict rules only imperfectly understood". As an improvement on this statement one could only hope for a word other than "art" to acknowledge more pointedly the contribution of the mind as well as of the eye, for the process must be reasoned and orderly. Matters of taste enter, but also far more.

GENERAL DESIGN

Should the structural design of a bridge be contemplated, immediately it becomes apparent that, while the live portion of the total design load may be known, the dead load, including the structure's own weight, can not be known accurately until the complete design has been effected. Furthermore, the dead load may be a major part of the whole. Thus an iterative procedure must be adopted and early gross estimates must be made, refined subsequently and re-entered into the solution. In more complex problems, which necessarily involve more compromises owing to the increased state of incompatibility resulting from the many more requirements, these initial estimates and decisions may be critical. They form the nucleus about which the final design is ultimately crystalized. With a high degree of compromise, no unique, optimum solution may be readily discernible. In such a case, only time and service experience can demonstrate the part that wisdom may have played in the initial stages.

Ships and aircraft are examples of such extremely complex problems. Not only are they structures, but vehicles as well. Furthermore, they are vehicles

whose efficiency or, in fact, whose very ability to perform at all, is strongly dependent upon weight economy. Quite obviously their structural loadings are of a dynamic nature and highly imponderable. Ships, because of their size, cost, and length of building time are built to any particular design in but limited numbers and no mock-up or test model can be afforded. Nor can the feedback of measured loading data or other service experience be more than a fraction as voluminous as for aircraft. Only fragmentary statistical samples are available. If, in fact, there is any more conservatism in the structural design of ships than in aircraft, it is hardly to be wondered at. But competitive economic pressures operate to limit any excesses. Despite the rigour of the limitations, the demand for the over-all optimum design solution is equally severe.

Figure 1 is an attempt, by means of a model, to display a rational over-all design procedure as applied to a hypothetical but typical, surface cargo ship problem. The purpose is to assist in organizing the thought process, having in mind particularly the use for such, so as to enable ship design problems to be solved most efficiently, and by means of automatic computers, if desired. The radial lines of the diagram represent the salient considerations of the designer arranged, it is believed, in the logical order most conducive of rapid convergence on the ultimate, refined and balanced solution indicated by the inner closed circle.

Achievement of this end result may conceivably be initiated from any of several points, but the preference expressed by the diagram is first for a rudimentary concept of the ship's general arrangement which will come to mind as soon as cargo density and the size of unit shipment are specified. A cargo density in the region of 45 ft.^{3}/ton seems to mark the boundary between those cargo ships designed as weight limited as opposed to those which are volume limited. The double hulled bulk ore carrier type is

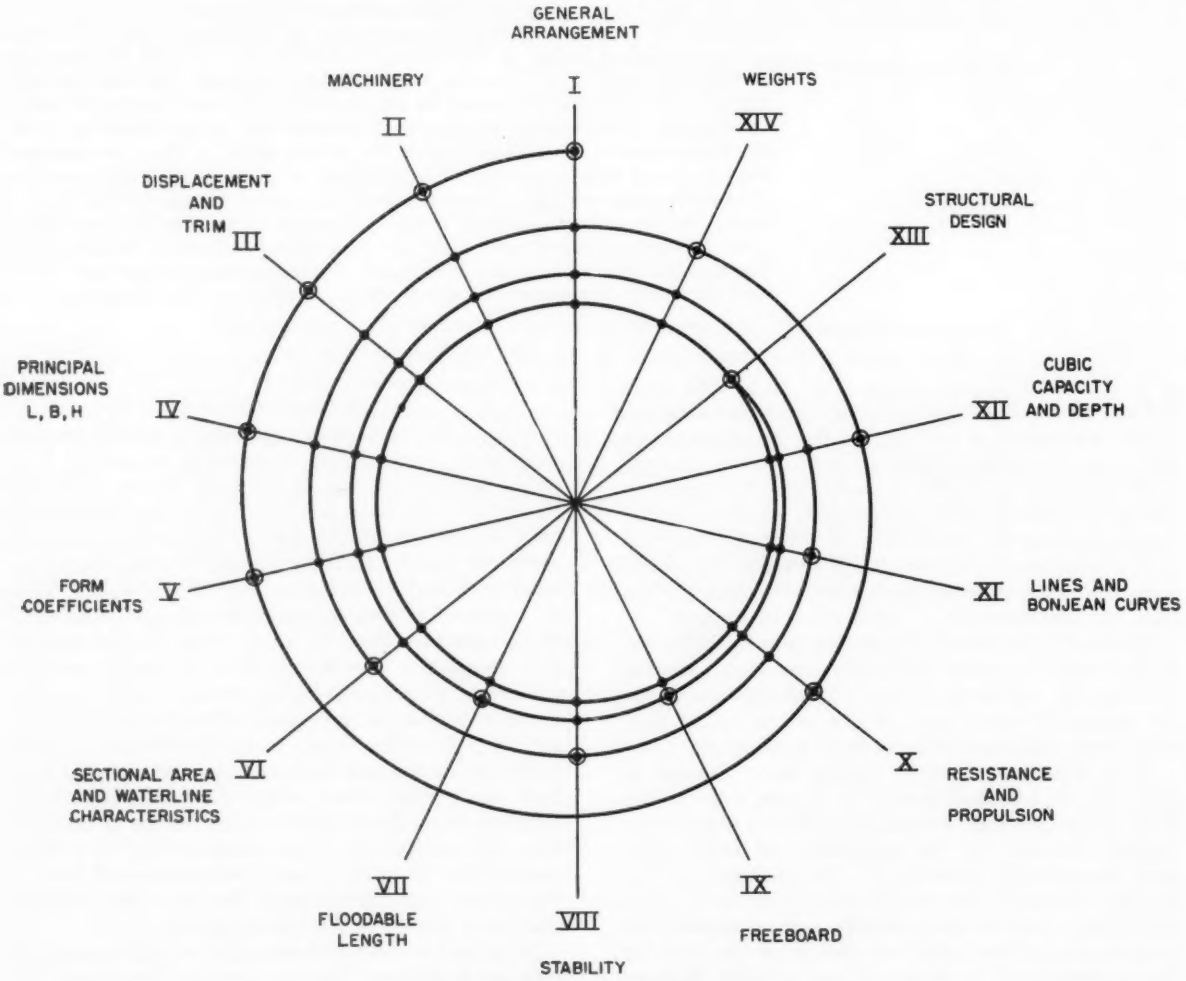


Figure 1. General Design Diagram.

characteristic of one extreme and the deep shelter decker of the other.

Also an arbitrary but tentative choice of the type of main propulsion machinery is a practical necessity.

Whether the vessel be a bulk or volumetric carrier, the deadweight ratio provides the first means of translating the cargo deadweight into a ship displacement and thus a first impression of ship's size is gained. This third consideration of the first design cycle may be conveniently designated III-1.

Gross estimates of the principal dimensions of the underwater form, viz. length, breadth and draft, follow naturally with some guidance from accumulated data on the geometric proportions of earlier, good designs.

The underbody form coefficients require attention at about this point and they are chosen most logically with resistance and propulsion in mind.

From such elementary beginnings some estimate of power requirements may also be made by incorporating the additional factor of speed required, as prescribed by the owner.

The depth of ship and topside characteristics then follow, to suit volume requirements, most of which will be devoted to cargo or payload of whatever type. Over-all hull form coefficients extrapolated from the underwater counterparts will be found useful for this purpose. The vessel's range of operation, plus the shaft horsepower previously estimated, permit evaluation of that portion of the volume to be occupied by fuel.

The foregoing procedures are not dealt with here in detail since they are well known and may be accomplished with the aid of such material as is presented in References 1 through 18, which list is by no means all inclusive. The rough outline is included simply to illustrate the manner in which, with proper sequencing, one item builds on others previously established and how it in turn will contribute to the solution of succeeding ship characteristics.

To complete the first rough hewn cycle, a preliminary light ship weight estimate must be made, probably in terms of the several major weight groupings such as hull steel, machinery and outfit which latter may be subgrouped depending upon whether it is variable with cargo, numbers of passengers and crew, or with size of ship. As references, the sort of data and the methods of items 3, 4, 9, 10 and 19 through 23 of the Bibliography will be of use and thus a new, somewhat more refined, estimate of total displacement will be possible which can also incorporate a more exact fuel oil weight now that a first estimate of power has been made.

In the foregoing remarks, it has been assumed that the owner's ship performance requirements have been set forth by his specifying, as a minimum, merely (1) total weight and density of cargo or payload to be carried, (2) vessel's speed and (3) length of voyage, these having resulted from an economic analysis of the owner's experience and future plans. Fixing additional characteristics, such as maximum draft, type of machinery, evaporator capacity, etc., although reducing the number of decisions to be made by the naval architect, may make the ultimate, absolute optimum design more difficult to achieve. In somewhat more specific naval architectural terms as applied to the general cargo carrier type, this optimum design will require that the vessel, when laden with the specified cargo plus fuel, fresh water and stores sufficient for the specified voyage at the specified speed, shall have all holds completely full and be down to her maximum limiting draft based on considerations of her freeboard, internal subdivision and strength of hull. In this "full and down" condition the cost of the voyage shall be a minimum, also the cost of construction, insofar as these are compatible. This represents idealized operation of the ship but it serves to clarify the issues involved. For design purposes, the naval architect should also assume the cargo to be homogeneous, i.e. having the same density in all holds unless the owner's requirements specifically dictate otherwise. This is the one inflexible condition of loading and thus it becomes the worst reasonable one. With a shipment of varying density, the manner of stowage can be made to improve transverse stability, trim and ship bending moment situations over the homogeneous cargo case. True, stowage of nonhomogeneous cargo can also make these situations worse but it need not do so.

Whenever the ship's desired performance characteristics fall within usual limits, the procedure outlined so far is more a matter of minutes than of hours, even if manually performed, provided a full range of background data is available and in readily usable form. Despite considerable reference to papers of value for this first phase of development, there is actually no substitute for such material having been analyzed and compiled by the user himself or with his full knowledge. This is because certain unifying steps will have been taken to reduce the information from each ship to some common basis for plotting and the user should be aware of their nature. In addition, ship data points of such a gross, over-all sort cannot be expected to plot as a well defined fair curve regardless of which simple coordinate system is chosen. The inference here is that any of several bases may be equally suitable for some of the data since any one by itself neglects parameters which may be important. The coordinate system to be preferred is the one which shows the greatest consistency among the points by minimizing their spread and most nearly aligns them along a fair curve. In the ultimate, however, it will still remain that a detailed knowledge of the unique idiosyncracies of individual ship spots is necessary in order that their compliance or noncompliance with the norm may be explained and the proper emphasis placed on the norm as representative of the

new design. Despite the practical problems indicated, reliance on unified data from many ships is preferable to dependance on one close prototype, even when the details of such a ship are available. The "weight equation" is a valuable means of emphasizing the interrelationship of different weight groups and the ballooning effect on displacement of adding to one. However its precision suffers markedly if the extrapolation from prototype to new design is anything but very small. Worse still is the danger of unwittingly perpetuating redundancies and other faults of the parent design along with its virtues.

In the figure, the intersections designated by circumscribed dots denote first considerations or estimates of these items. A simple, solid dot indicates that the previous estimate of that item is verified or modified to suit changes at other points made earlier during that cycle and using more complete information and more precise methods of calculation wherever available and warranted. Relocation of a point on a radial line (or the error of closure) is evidence that a change in the previous estimate of that item has been made or that some new information has been added. Thus, each succeeding spiral represents a more and more refined and firmly crystallized conception of the ultimate design.

On the assumption that, in this hypothetical example, there is no call for changes in displacement and principal dimensions great enough to radically disturb the other first cycle estimates, the underwater sectional area curve and the waterline shape should be developed as indicated at VI-2. (References 1, 24 and 35)

The most elemental measure of a vessel's stability is given by its transverse metacentric radius and this may be obtained by locating the instantaneous metacenter from the geometry of the underbody and estimating vertical centers of gravity for component weight items of the deep displacement and amalgamating them to give the over-all center in the usual way.

In reconsidering power requirements under X-2, it is probably not too early to make use of residuary resistance data such as found in Taylor's work (Reference 25) or in the Series 60 hull family (Reference 26).

Appropriate to XI-2 is the delineation of a small scale ship's body plan including only a few stations. The sectional area and waterline curves of VI-2 provide the basis. These "lines" should extend to the upper deck so that an underdeck area curve showing the fore and aft volume distribution within the hull may be obtained. From this will come the first reliable estimates of cargo cubic.

Any preconceived notion that the machinery space will be located amidships may well be examined with reconsideration of the internal arrangement under I-3 and a decision may be forthcoming from the study of machinery layouts at II-3 and the deep displacement trim calculated at III-3.

In vessels carrying more than twelve passengers an analysis of floodable length is mandatory, of course, but in other cases also it may be felt desirable. Webster's approximate method (Reference 27) has the advantages of being quick and simple. Wherever the margin line follows other than a standard parabolic sheer, however, its results are questionable, especially toward the ends of the ship.

A shorthand approach to the legal freeboard determination (Reference 28) is hardly worthwhile as the full calculation is not lengthy. If, thereafter, significant changes are made to the vessel's characteristics, they may be reinserted into the original computation quite readily.

At X-3 it may be advantageous to select the basic characteristics of the propeller and, as a result, an improved extrapolation from effective horsepower to shaft horsepower should be possible. The uncertainties remaining in this procedure presently are the prediction of thrust deduction and wake.

Consideration of the ship's tonnage (Reference 29) is anticipated at XII-3.

By XIII-3 the basic structural elements such as midship section and typical bulkheads should be available for whatever aid they may afford in making possible weight estimates from a more detailed breakdown as desired for XIV-3.

The "light and air" space anomoly in present tonnage regulations may make minor arrangement alterations in the region of the machinery space beneficial. Also, at about I-4, detailed deck and cargo handling layouts are necessary. Cargo handling is of such importance to the operation economics that its first consideration should have been included in the early arrangement studies.

At least in steam power plants, optimization of over-all thermal efficiency through the selection of the component parts is a matter worthy of investigation at II-4.

For the purposes of this illustrative outline it will probably be sufficient to mention only a few additional points. A floodable length calculation by one of the "exact" methods is intended at VI-4 and at VII-4 curves of statical and dynamical stability are presumed. For passenger vessels the necessary analysis of stability in damaged condition falls most naturally in this cycle.

As a final refinement to the power estimate, propeller performance, underwater form or seaway performance, towing tank model tests are uniquely valuable.

The figure attempts to show that after a sufficient number of design cycles has been negotiated the differences involved become so small as to be insignificant. Ultimately all the mutually dependent variables are in accord and the final refined and balanced design is achieved. The closure is shown here to occur with the structural design but this is of no significance and might just as well have been at any other point.

The last cycle could appropriately be designated

the "analysis" cycle as the processes taking place within it are in the form of analyses of characteristics previously established and the design is reshaped from the findings. The first cycles are synthesizing stages and from this interplay it is clear that both thought processes are essential to the final objective.

Considerable confidence is felt with the order of operations presented here for application over a wide range of merchant ship types. However, unique conditions for some types may make it desirable to perform certain of the detailed estimates during earlier cycles than in the illustration. For example, with a dense cargo carrier it may be advisable to determine the freeboard limit sooner whereas, with an extremely light cargo, stability considerations may be uncommonly critical. Furthermore, a few matters of not such general concern and not included in the figure may dictate some design aspects in other special cases. In passenger ships, fire protection requirements must be complied with. With high powers, vibration becomes of more importance and it is possible that some preventive steps may be taken in these design phases. Of somewhat more universal interest are the light draft ship characteristics in which connection Comstock's data of Reference 30 should be noted.

As an incidental comment, it might be added that a filing system for design data based on the dual numbering system adapted herein has been found very convenient, and it appears to offer some promise for use with library coding and retrieval or similar techniques of electronic data processing.

For the design now in hand, the type of power plant was held constant. For any others which are pertinent, a similar design iteration is required to account for the differing fuel rates and specific densities, machinery weights and the like. From among them the final solution may be made or at least the direction for further studies is clarified. As another independent variable, if the machinery space location has been a subtle matter, it will be advisable to work out the over-all ship design in some detail with the various locations fixed for each.

Returning once more to the model . . . . The peripheral cycle is clearly indicative of the infinite wideness of choice available to the initiating preliminary designer but with each round the maneuvering room diminishes and the latitude for change becomes smaller as, in fact, do the alterations deemed necessary. The smaller amplitudes and the increasing amount of labor involved in each successive spiral make it both possible and necessary to increase progressively the concentration of man power until numerous subgroups may be proceeding simultaneously and independently to analyze the aspects in which they specialize. In the sense that a modification may be wrought in some area of the total project as a result of his development, even the detail draftsman may contribute to the final stages of "design." Thus the several man hours of the first cycle advance to hundreds of thousands in the last. (Now the model has a third dimension—an altitude in terms of man hours—and has become a truncated conical spiral, but the scale had better be logarithmic!)

Some of the contributory studies appropriate for the late design stages may themselves be conceived as operations research problems and treated so with advantage. In fact, the ones in mind are already well advanced toward the possibility of programming. The steam cycle, heat balance analysis of II-4 is one of these and a suitable analytical optimization method for it was presented before the New England Section of the Society of Naval Architects and Marine Engineers in May 1959 by E. C. House and B. J. Wooden.*

STRUCTURAL MIDSHIP SECTION—LONGITUDINALLY FRAMED

The structural design of longitudinally continuous material amidships, appropriate to XIII-3, is another. Where the fore and aft stiffening members are more closely spaced than the transverse, as in a typical longitudinally framed ship, St. Denis in Reference 33 has presented an orderly approach applicable to naval practice. For longitudinally framed merchant types a similar procedure should be found usable but criteria insuring the satisfaction of classification societies have yet to be completely worked out.

Figure 2 is a representation of the general method expressed in the flow diagram form of Figure 1. First, tentative and arbitrary spacings of transverse web frames and longitudinals must be selected

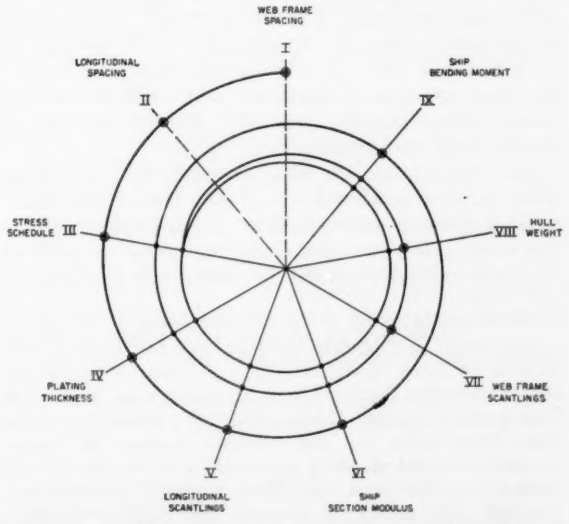


Figure 2. Midship Section Structural Design Diagram —Longitudinal Framing.

* This paper also contained an interesting example of an optimized general design study.

which thereafter are held constant and provide the basis of that particular solution. Thus the corresponding radial lines I and II are shown dotted to indicate that, once established, they are not reconsidered with each cycle. In an operations research analysis, these are the restraints.

In brief, limiting values for three types of stress are established (III-1). With the first assumption that the longitudinals and web frames form panel boundaries of the plating which remain plane, these strength limits together with instability considerations result in two estimates of required plating thickness (IV-1). The more severe requirement rules, of course. Both strength and instability criteria are also used to determine scantlings of the longitudinal stiffening members which are subjected to tensile and compressive loads as the ship hogs and sags (V-1). When all longitudinally continuous plating panels and longitudinals have thus been tentatively sized to meet their local conditions, the ship section modulus may be found (VI-1). A first estimate of ship girder bending moment (IX-1) may be sufficient to indicate whether or not the section modulus is adequate or must be increased to keep the ship bending stress within its limit. Locating the true position of the neutral axis may, by itself, bring about minor scantling changes from those based upon the originally assumed position of the axis. As modifications and balancing proceed toward refinement, the transversely oriented stiffening members are sized (VII-2) and a good estimate of hull structural weight can follow (VIII-2). This enables calculation of a more exact bending moment (IX-2 or IX-3) and another cycle begins.

Here again, of necessity, the early design steps depend on simplifying assumptions and elementary relationships to yield a result on which the analyses of the last cycles may operate. As in the gaining of all significant new knowledge, this is the universal two-step process of proposal and criticism which ideally must contain precisely correct degrees of imagination and practicality.

For optimizing, several independent solutions with varying combinations of web frame and longitudinal spacing are necessary. Structural weight is the most valid, first basis of comparison as well as the most straightforward for quantitative purposes.

STRUCTURAL MIDSHIP SECTION—TRANSVERSELY FRAMED

Although it is hardly likely, if the framing system is also an open question, the optimum solution for the transverse framing system must also be found. The author's paper (Reference 34) presenting a design integration for the midship section of transversely framed ships is suitable, and Figure 3 is a model of the method. The typical transversely framed ship afloat at present has only very few, widely spaced longitudinally continuous stiffening members and of these, by law and by classification society practice, rightly or wrongly, only the vertical keel is given credit for contributing to longitudinal strength. The figure is therefore slightly simpler. Furthermore, several of the detailed methods of calculation are different as well as the loadings and criteria which, in their present form, have been developed to satisfy the requirements of a classification society, namely the American Bureau of Shipping. Values for any other standard or in compliance with new knowledge can be found easily.

Having made a tentative selection of the spacing of transverse frames, in broad philosophical terms, the method developed in the paper proceeds as before with each cycle building on information generated in the ones preceding. The stress schedule as such is not employed in the paper, but its effect is included in the formulations given.

As regards the merchant ship bending moment, a somewhat frustrating situation exists in that, even should the bending moment be unusually small in a particular ship, there is a lower limit on ship section modulus which will apply and is imposed by law or classification society edict. In such a situation, the calculation of bending moment serves only to enable the naval architect to decide if, in his judgment, a greater section modulus than the mandatory one is desirable.

Many transversely framed vessels of current design employ a closer spacing of intercostal side girders than formerly was usual. This is entirely fitting and is no doubt a trend which will be perpetuated. However, with this development, many primary-structure plate panels will have aspect ratios less than three to one, in which case the critical strength of the panels becomes a much stronger function of the spacing of these longitudinally continuous members forming the fore and aft panel boundaries and the exact spacing must be reckoned with. In time it is reasonable to expect that the contribution of the longitudinals to ship girder strength will also be acknowledged although this may take international action.

Provision for these modifications is indicated in Figure 3 and it then becomes similar to Figure 2 in its superficial aspects.

The model similarity as between Figures 2 and 3 makes it possible to adopt the solution outline for a wide combination of the two basic systems and from one or the other (Reference 33 or 34) detailed procedures which are suitable can be taken. For a complete optimization, therefore, the parameters can be: type of framing system, spacing of longitudinals and web frames, or floors, side frames and side girders. Basically, when found, the net scantlings should be increased in the amount of a corrosion allowance as desired. Actually, the expressions of Reference 34 have already included it.

The general impression intended by this discussion is that a framework exists which should permit solution of the over-all ship design problem and several of its most important subsidiary design

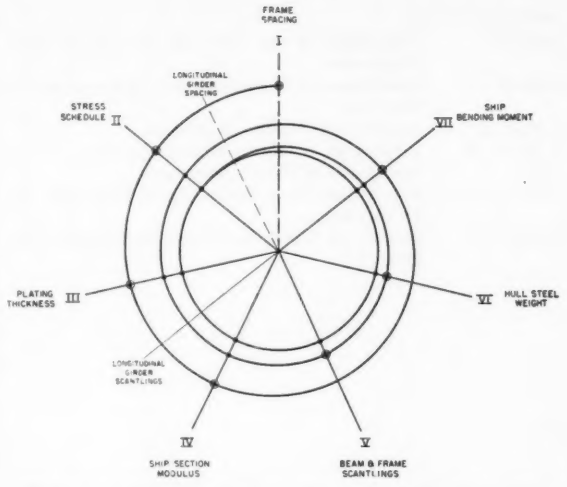


Figure 3. Midship Section Structural Design Diagram —Transverse Framing.

problems by operations research methods if desired. No oversimplification of the development still necessary is intended, although the impression may have been given that the end result is more immediately possible than is actually the case. It is clearly understood that one or two minor dislocations still exist and that much design information now in graphical form must be expressed in different terms and perhaps even be reanalyzed. Some operations within the primary model necessitate a small amount of drafting so the process is intermittent. Furthermore, the exact use of the Figure 1 model will not be ideal in all its aspects for design of extreme or unduly restricted character. A sequence of complex analyses will be required before this bare outline is filled out and readied for completely automatic solution. But even as things now stand, it is hoped that some clarification of design processes and problems has been achieved.

On the other hand, the structural models already are so far advanced as to be almost immediately usable in automatic computation. With modern computers, structural optimization is now possible (and on a much broader base) despite the pressure of production schedules.

The ordering of thoughts attempted here implies agreement with a statement of Herbert Spencer that "If a man's knowledge is not in order, the more of it he has the greater will be his confusion." Few, if any, of man's creations offer as many opportunities for the embodiment of such a wide range of man's knowledge as does a ship.

Yet the philosophy expressed visually by the models is not confined to ship design. It has much broader implications and is bounded only by the word "design" itself and it alone.

BIBLIOGRAPHY

1. Comstock, J. P., "Introduction to Naval Architecture", (Part II).
2. Ridgely-Nevitt, C., "The Development of Graphic Aids to Preliminary Design", A.S.N.E., May 1950, p. 303.
3. Bustard, E. E., "Preliminary Calculations in Ship Design", N.E.C.I.E.S., 1940-41, p. 179.
4. Schokker, P. C. A., Nuverburg, E. M. and Vossnack, E. J., "The Design of Merchant Ships".
5. Munro-Smith, R., "Ship Design—Preliminary Determination of the Dimensions and other Technical Characteristics", The Shipbuilder and Marine Engine-Builder, October 1956, p. 585.
6. Calder, J. D., "The Length/Beam Ratio", Shipbuilding and Shipping Record, September 16, 1954, p. 369.
7. Witte, N., "Die Entwurfrechnung fur Frachtschiffe", Schiff und Hafen, March 1955, p. 123.
8. Diede, G., "Entwurf von Linienrissen fur moderne Handelschiffe", Schiff und Hafen, February 1956, p. 85.
9. Benford, H., "Engineering Economy in Tanker Design", S.N.A.M.E., 1957, p. 775.
10. Benford, H., "Ocean Ore-Carrier Economics and Preliminary Design", S.N.A.M.E., 1958.
11. Munro-Smith, R., "The Design of Coasters", Shipbuilding and Shipping Record, July 24, 1941, p. 79.
12. Todd, F. H., "The Fundamentals of Ship Form", I. Mar. E., 1944-45, p. 1.
13. Ayre, W., "The Propulsive Efficiency of Cargo Ships", I.E.S.S., 1931-32, p. 179.
14. Troost, L., "A Simplified Method for Preliminary Powering of Single Screw Merchant Ships", S.N.A.M.E., 1957, p. 737.
15. Minorsky, V., "A Nomograph for the Preliminary Powering of Merchant Ships", International Shipbuilding Progress, Vol. 2, No. 9, 1955, p. 226.
16. Bocler, H., "The Position of Longitudinal Centre of Buoyancy for Minimum Resistance," I.E.S.S., 1953-54, p. 11.
17. Allan, J. F., "Improvements in Ship Performance", I. Mar. E., 1953, p. 117.
18. Munro-Smith, R., "The Determination of Cargo Capacity and its Centroid", The Shipbuilder and Marine Engine-Builder, April 1958, p. 205.
19. Arnott, D., "Design and Construction of Steel Merchant Ships", Chapter II(A).
20. Powell, S. C., "Estimation of Machinery Weights", S.N.A.M.E., 1958.
21. Telfer, E. V., "The Structural Weight Similarity of Ships", N.E.C.I.E.S., 1955-56, p. 123.
22. Robinson, H. F., Roeske, J. F. and Thaeler, A. S., "Modern Tankers", S.N.A.M.E., 1948, p. 422.
23. Henry, J. J., "Modern Ore Carriers", S.N.A.M.E., 1955, p. 57.
24. van Lammeren, W. P. A. and Troost, L., "Resistance, Propulsion and Steering of Ships".
25. Taylor, D. W., "Speed and Power of Ships".
26. Todd, F. H., Stuntz, G. R. and Pien, P. C., "Series 60—The Effect upon Resistance and Power of Variation in Ship Proportions", S.N.A.M.E., 1957, p. 445.
27. Webster, G., "Subdivision of Passenger Vessels", I.N.A., 1920, p. 234.
28. U. S. Coast Guard "Load Line Regulations".
29. U. S. Treasury Dept., Bureau of Customs, "Measurement of Vessels".
30. Comstock, J. P., "Charts for Light-Draft Form Characteristics", Marine Engineering and Shipping Age, November, 1926, p. 639.
31. Baker, L., "Some Factors in the Selection of Machinery for Cargo Liners", I. Mech. E., 1955, p. 17.
32. Stewart, W. A., discussion of symposium "Advanced Machinery Installations Designed for the Maximum Saving in Weight and Space", I. Mar. E., 1955, p. 335.

33. St. Denis, M., "On the Structural Design of the Midship Section", David Taylor Model Basin Report C-555.
34. Evans, J. H., "A Structural Analysis and Design Integration—With Application to the Midship Section Characteristics of Transversely Framed Ships", S.N.A.M.E., 1958.
35. Todd, F. H., "Some Further Experiments on Single Screw Merchant Ship Forms—Series 60", S.N.A.M.E., 1953, p. 516.

ABBREVIATIONS

A.S.N.E.	JOURNAL of the American Society of Naval Engineers
I.E.S.S.	Institution of Engineers and Shipbuilders in Scotland
I. Mar. E.	Institute of Marine Engineers
I. Mech. E.	Institution of Mechanical Engineers
I.N.A.	Institution of Naval Architects
N.E.C.I.E.S.	North-East Coast Institution of Engineers and Shipbuilders
S.N.A.M.E.	Society of Naval Architects and Marine Engineers.

In a survey of the science of Undersea Warfare (USW), some of the possible salient features of the future are as follows:

—Underwater weapons with speeds up to 250-300 knots.
—Submarine carried anti-missile missiles to combat high speed torpedoes and missiles.
—45 knot hydrofoil craft for coastline ASW work.
—Underwater-to-surface missiles which will permit the submarine to attack a surface pursuer.
—Drone helicopters for search and attack operations against submarines.
—Submarine launched anti-aircraft missiles.
—Anti-POLARIS missiles designed to attack submarine launched missiles.
—Long range ASW weapons which could be fired from hundreds or thousands of miles.
—Fixed submerged missile bases, anchored to the ocean floor, which could be launched by remote control.
—Submarines and weapons capable of operating at great depths—up to 10,000 to 20,000 feet.
—Decoy missiles designed to divert an attacking missile from its target.
—High speed underwater drones for training.

—from MISSILES AND ROCKETS
August, 1959

THE PROJECT MANAGER . . . HIS ROLE IN ADVANCED TECHNOLOGY INDUSTRY

ACKNOWLEDGEMENT

Paul O. Gaddis, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, is the author of this article. It was published in the July 1959 issue of "Westinghouse Engineer".

ORGANIZATION by project—the welding together of various talents to achieve a specific, tangible goal in a limited time—is a familiar and oft-used technique. In technical development, the project frequently consists of scientific, engineering, manufacturing, and supporting personnel, and is intended to achieve a relatively short-term goal. The increasing complexity of modern technology, however, and the increasingly common necessity of working at the frontiers of scientific knowledge have resulted in a new type of project—the so-called *advanced technology project*. With this has come the need for a new type of manager, with the necessary skills to meet the unusual challenges involved.

This new breed of manager is easy to identify in rapidly growing new fields, such as electronics, astronautics, and nucleonics. Generally, his project's goal is to create an advanced product, and most often this is a product requiring a large measure of technical pioneering. The primary tool available to him is the brain-power of professional specialists in diverse fields; he uses this tool in all phases of the creation of his product, from concept through initial test operation and manufacturing stages.

Several other characteristics help distinguish the advanced technology project: Its success frequently requires rapid conversion of the most recent discoveries of fundamental research into "hardware"; the development phase of the project frequently occupies a substantial portion of the project time; and, the man-power "mix" is likely to include an unusually large number of scientists and engineers.

THE ADVANCED TECHNOLOGY PROJECT MANAGER . . . WHAT MUST HE DO?

In learning to manage a group of professional employees, the usual corporate boss-subordinate relationship must be modified. The "how"—the details or methods of work performance by a professional employee—should be established *by the employee*. He must be given the facts necessary to permit him to develop a rational understanding of the *why* of tasks assigned to him. Moreover, if this employee is to be treated as a professional, high performance standards must be established for him, and he must be accountable for productivity at the professional level. In turn, he may be granted the prerogatives of a professional—freedom from detailed supervision, freedom from administrative routine where feasible, and working quarters that afford privacy

and comfort. At the same time he must never be excused from the responsibility of having to *produce* in accordance with the exacting requirements of his profession.

A second unique aspect of the project manager's job is that his task is finite in duration. Unlike most managers, he is not privileged to see a reasonably long line of repetitive or similar functions stretching ahead of him. Nor can he modify his assembly line to manufacture a new product. He is managing a specific group of advanced specialists; the professional "mix" of his group is tailored specifically for the accomplishment of a mission.

If the project manager and his group are successful performers, they will complete all facets of their job—and thereby work themselves out of a job—in the shortest reasonable time. This may be a year or less, or five years and upward for long-range, high-budget projects. In any case, the project manager must trust his corporate management, implicitly in most cases, to provide him and his forces with continuity of work.

Another unique feature of the project manager's job is the absence of "feedback" information during the early stages, and often other stages, of his project. Under the servomechanism analogy of management control, a manager establishes a closed loop in which the performance output of his group is fed back to him, and compared with performance standards; corrective control action is then directed into the system. However, in advanced-technology work, during the design phase of a project and before test results of newly developed equipment are available, the project manager often finds himself like a pilot flying blind assisted by a relatively unproven set of instruments. His experience, judgment, and faith must carry him through until early test results become available, and from this first "feedback" he can modify the design approach in a direction most likely to meet the acid requirements of further proof tests. Meanwhile, during these periods of blind flying, he may be forced to make decisions that commit substantial funds or involve long-term commitments.

Essential to the project management concept is a clear delineation of authority and responsibility. The manager knows that his basic responsibilities are to deliver his end product (1) in accordance with performance requirements, (2) within the limitations of the budget provided him, and (3) within the time schedule specified by his customer. In general, the manager delegates by tasks, so that subordinate managers within his group have these same three responsibilities for sub-projects. Success or failure may well hinge upon the manager's ability to discern fine variations in emphasis and resolve the continuous apparent conflicts among these three basic responsibilities.

During the life of an average project the relative importance of each responsibility may change several times. Woe unto the project manager whose interpretative apparatus is out of tune, or who for any reason fails to stay in phase with the governing one of the three basic responsibilities. Overemphasis on schedule may be fatal when dollars have become the governing requirement, or vice versa. Likewise, performance requirements must be met or trimmed to fit reality. The skillful project manager aims for a balanced emphasis upon the three responsibilities and maintains a position of sufficient flexibility that he can shift emphasis to meet circumstances.

Like the line manager, the project manager is at once a man of action, a man of thought, and a front man. As a man of action, his most important function is to establish and preserve a sense of momentum throughout all layers of his project. He must strive to avoid "dead center" situations in which general inertia seems to become overpowering and his technical people for the moment see no direction to advance. Thus, the usual management function of trouble shooting, or of unraveling the knots, occupies much of his time.

The first-line supervisors—the "supervising engineers"—are by definition the men who play the key roles in guiding the day-by-day progress of a project toward its goals. Such a supervisor often bears the same range of burdens borne by his manufacturing counterpart; demands upon his time can easily be overpowering if the project manager does not shield him from diversionary requirements. An illuminating experience for a project manager is to portray on a chart the number of line, staff, and customer offices that a supervisor must deal with in accomplishing his tasks.

However, a major danger lies within this supervisory situation. In attempting to shield a supervisor, to free him to concentrate chiefly upon the vital engineering job at hand, the project manager can unknowingly deal a severe blow to the supervisor's advancement potential. The manager must realize that the supervisor is at a critical point in his career, at which leadership capability and administrative potential can blossom or can be blighted. A general and basic tenet of management—the training of individuals for leadership—must not be shelved merely because the pace of an advanced-technology project seems at times to be overpowering.

In pursuing his objective of maintaining momentum, the project manager must be constantly aware of the apparent disdain for time commitments by some theoretically inclined scientists and engineers. While this attitude is a rather deep study in itself, one factor that must be understood is the drive for perfection in this kind of professional. Any kind of promised delivery date inevitably involves a compromise with perfection, in that the product or study must be cut off, wrapped up, and delivered at that point, thereby leaving dangling the further im-

provements the theoretician has come to anticipate. If allowed to run rampant, this tendency can result in continuous postponements of output.

As a man of thought, the project manager must be an organizational planner and an advance planner (within the time scale of his project). The crux of effective performance of a project lies in the interrelationship between organizational structure and individuals.

Skill in the somewhat mystical art of organization planning pays off for the project manager. This involves the correct tailoring of organizational structure to available individuals, and vice versa. Although the organizational structure of a project is important, if not vital, it will not make up for inadequate caliber of technologists within the organization. Conversely, poor organization structure can tie up the output of topnotch engineers and scientists.

In advanced technology, sound organizational planning requires recruiting adroitness to acquire scarce talent both from within and without the parent organization. It involves the ability to utilize some engineers and scientists who do not measure up to reasonable requirements for the project—the ability to shape a team that can play over its head when necessary. Organization planning in a project cannot be done without a thorough understanding of the personalities, characteristics, and attitudes of the technologists, both of academic bent and practical bent, and both as individuals and as members of their particular professional methodologies.

In the matter of advance planning, the paramount duty of a project manager is the avoidance of crises that manifest themselves during the design, manufacturing, and check-out stages. Perfection will never be attained, and the best efforts of the manager can only reduce, but never eliminate, these crises. While the technological crisis has become accepted as an inherent part of advanced-technology projects, each of these crucial periods leaves residual effects. First, the resolution of the crisis generally involves a sacrifice of engineering principle for expediency, which may in turn lead to subsequent crises. Second, each crisis, with its resultant need for immediate solution, erodes the constructive attitude of the project's engineers and scientists, particularly the theoreticians. Therefore, the project manager must avoid crises wherever possible, and when they come he must fend off the ill effects as best he can. Unfortunately, *most* crises during the course of a project can be traced to lack of adequate advance planning.

At any time during the course of the project, the manager may be called upon to act as front man to help shape or reshape the policies that affect his project relative to the corporate structure and objectives. Contrary to uninformed opinion about the advanced-technology industries, "selling" is a never-ending job of a project manager. In acquiring scarce people, or scarce materials, the project manager must always be able to make an effective presentation, often on short notice. Many project managers have suddenly found themselves, in midcourse, fighting for the very existence of their project. While the outcome of many of these struggles is often beyond the influence of any actions taken by the manager, in other cases his actions as a fully informed representative of the project have a profound influence on the eventual outcome.

THE PROJECT MANAGER . . . WHAT MUST HE BE?

In discharging his three basic responsibilities—to deliver a product that works, within budget, and on schedule—the project manager must be oriented to corporate management. He must not fail in these responsibilities or he cannot survive. He must understand corporate management; he must be at home in the economic dimension in which business operates, and he must understand the evolution of corporate policy and the nuances of its interpretation. His temperament and personality should be of a nature likely to gain respect in the front office for the project's problems.

Also vital to continuing success in project management is the manager's skill at providing an environment in which the productivity of the scientists and engineers is nurtured and maintained. If the project manager is to provide this critical environment, he must understand the role of the professional as an employe in industry, and the professional's reactions to modern corporate organization. These reactions have posed many broad problems, and if the manager is to be well informed he should be a student of current investigations on the topic. The handling of the problems of professional personnel may be the deciding factor in the success or failure of many companies in advanced-technology industry.

One of the honored cliches of the business world has been paraphrased in our new industries: "The only thing wrong with advanced-technology industry is advanced-technology people." These words are descriptive, but misleading. For in the new industries the people, more than ever, *are* the business. A company's material resources are of secondary importance compared to the caliber of its professional managerial and technological staff.

To establish a productive environment, the manager must be oriented to technology and to his technological employees. Otherwise his project will not prosper and he will eventually fail. A project manager is the man in between—the man who must possess a working understanding of two camps. He must serve as the mechanism for accomplishing the aims of his corporate management, at the same time serving as a perpetual buffer, so that engineers and scientists can meet the technological objectives that only they can define and only their output can meet.

"Projectitis" is a common difficulty; this is seeing all things as though a particular project were the

center of the corporate universe—the alpha and the omega of the development effort. The project manager needs a modicum of projectitis to generate the necessary drive and momentum to spark the project to success. These symptoms of projectitis will be observed by his corporate management, but they will expect this malady and will themselves suffer with acute outbreaks from time to time.

However, when dealing with his engineers and scientists, the project manager must not suffer, or appear to suffer, from any blind case of projectitis in establishing schedular aims and policy objectives. If he does succumb to this tendency with his own people, perhaps as a result of pressure from an afflicted management, at least two adverse results may occur: (1) the technological advancement in the development of his product, which is actually the most basic of the project's responsibilities, will suffer; and (2) the human resources of the project —the most basic and important resources in advanced-technology industry—will be reduced in efficiency and show symptoms of the discontent that affects productivity.

The subject of communications deserves much attention in project management. The theoretically inclined technologist, generally a man of imaginative creativity, and often his engineering brother with a more factual creativity, regard the right to communicate as the bread of life for an adequate scientific career. Related to this principle is the cherished right to publish scientific work for the judgment of one's scientific peers.

Yet a contradictory element appears in the scientists' attitude toward communication. Observation of any professional technological group will show that some pay only lip service to the ideal of free communication, and in reality are more than hesitant in communicating the results of their work, or their attitudes or feelings on any topic, to anyone connected with administration. Dr. Vannevar Bush in his book *Modern Arms and Free Men* noted the distinctly different reactions to communications that he observed among military men on one hand and among academicians on the other. In the military, vigorous and open debate on proposed actions took place before the decision. But when an office with clearly constituted authority made the decision, the antagonists, acting under a basic doctrine of their profession, swung around to support actively the idea they had opposed. In contrast, under the customs prevailing in academic circles, the duly established decision signals the start of the fight. In this environment, it is difficult to learn the nature of the opposition to administrative planning, since academicians are not inclined to communicate freely in such matters. Consequently, after decisions are drawn there tends to be considerable passive and sometimes active resistance in the execution of these decisions.

The lessons here for the project manager are plain. He must expend considerable effort in learning to communicate adequately with his scientists, and in developing the communicative attitudes of his engineers. Scientists and engineers who work in the operating environment, and who practice advanced-technology development, *can* adapt their output to mesh with corporate schedules and corporate budgets, if they are *adequately informed* regarding corporate policies and objectives. Budgets and schedules must not be mere edicts, but should be carefully prepared within the cognizance of and with the aid of the technologists who must live by them. Occasional arbitrary actions originating in the realms of policy should be explained as carefully as possible, and on this basis will be accepted and implemented.

The temporal aspect of a project manager's task may strain his capacities in the art of human relations. Because the duration of a project is well defined, scientists and engineers will anticipate their next assignment, even though it may be a year or more away. This tendency can result in a kind of divided allegiance, in which the engineers look to others outside the project who may be able to help them in gaining their next assignment.

The project manager must counter this tendency to cast about for the next task, or it will diminish his effective control of the present task. The manager must be bulwarked by a potent company sales policy, which has provided and will continue to provide new projects for professional employees. When he has this backing, the manager need only follow a basic rule of managerial conduct—that of letting his people know where they stand. Frankness and integrity in discussing the future will allay their instinctive concern about the job that is over the horizon, and convince them that their role in future projects is assured unless they have been told otherwise.

APTITUDES OF A PROJECT MANAGER

In examining these qualifications that a successful project manager must possess, the prerequisite training needs become apparent. The qualifications can be generalized as follows:

1. The project manager must be bred in the advanced-technology environment, so that he understands the pace, the people, and the relationships among contractors, subcontractors, and clients.

2. He should have a working knowledge of many fields of science, which he can augment when necessary to delve into the intricacies of a specific technology. He should have an inquiring nature and keep up to date in the many developments taking place in all advanced-technology fields. In regard to his knowledge, he should understand the fallacy of the oft-repeated concept that goes something like this: Scientists and engineers can respect only persons who are better scientists and engineers in their particular technologies, and by implication therefore, scientists and engineers cannot respect administrators, even those of technical

grounding. If this were true, anarchy would exist in advanced-technology industries, because it is becoming increasingly impossible for one man to master sufficient technologies to obtain general respect under this theory.

3. He must have a good understanding of industrial administration and sales, and have the qualifications of temperament and character that qualify a man generally for industrial management. He must understand the effects of policy as evolved in large organizations, since he will be working with industrial and governmental groups of large size and of considerable power. Importantly, he must have an understanding of *profitability* in the new and sometimes strange aspects it has assumed since World War II in the advanced-technology industries. This involves a thorough knowledge of the contractual mechanisms used to accomplish advanced-technology work—the fixed-price contracts, cost-plus contracts, and surely the "cost-minus" type of contract often referred to with acrimonious humor.

4. He must have the requisite faith and stability to carry him through the periods of blind flying when there is no feedback indicating the performance of his group nor of the products they are developing.

5. He must know the functions of each corporate staff specialty, and its relationship to his project. Generally he must alleviate the pronounced lack of understanding that his technological personnel will exhibit toward these staff groups. For example, purchasing is an important staff function affecting most projects. In buying many specialized components the typical project runs into a variety of purchasing problems, and their resolution can make or break the project's budget and its schedule. The project manager must also develop good two-way communications with corporate budget and fiscal planning groups, so that the project needs can be factored into corporate financial planning and so that the project can always be aware of current budget status. He must be able to talk the language of the comptrollership.

During the course of its lifetime, a project will be involved with corporate legal staffs and will find that a marked dearth of precedent exists in fields like nucleonics and astronautics. There will also be periodic negotiations with the personnel department, with its traditional difficulties in operating effectively where professional people are concerned.

6. The project manager must always remember that training is one of his basic responsibilities. In advanced-technology work, with its emphasis upon schedule and work output, the teaching aspects of management can be unduly subordinated. Under the concept of training responsibility, the manager must continually consider the preparation of first-line technical supervisors for further advancement into administrative roles. Likewise, the supervisor must be bolstered in providing the opportunity for professional and administrative improvement to the engineers and scientists within his group.

THE INTEGRATIVE AND ANALYTICAL MIND

In reviewing these qualifications, observe the emphasis upon the *integrative* function in the operations of the project manager. The requirement for the joining of many parts into a systematic whole is ever present. Integrative minds coordinate the productivity of all the functions in industry, and from the integrative mind industry receives its true directional guidance.

The processes by which the integrative mind works are largely indefinable, much as the requisite qualities for managerial personnel are not subject to scientific definition. Certainly the integrative mental processes must deal with intangible as well as tangible factors, and at times an intuitive process is needed in the formulation of judgment and decision. For instance, the highly complex reactions of human beings, at best only partially understood in our modern knowledge, must be thoroughly evaluated in most management decisions.

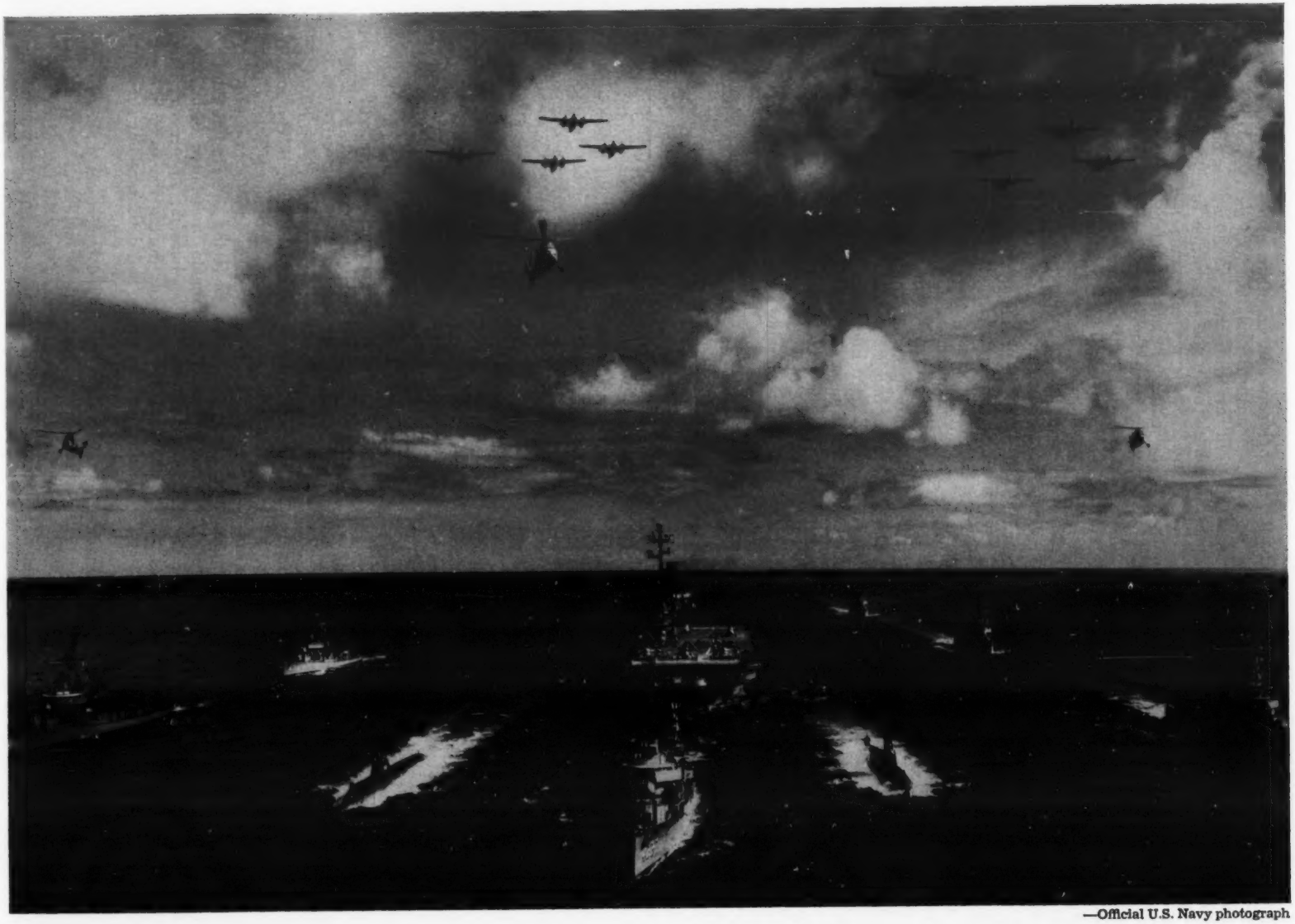
Conversely, a mind that is predominantly *analytical* wants to work only with facts that can be proven, and preferably in a specialized field of inquiry. The methodology of scientific analysis and experimentation has been carefully developed over many years, and is a part of the indoctrination of young men in training for a scientific career. This indoctrination breeds a distrust of intuition and a tendency to disregard intangibles. Further, the analytical mind will not draw its hypothesis until all relevant data have been observed and interpreted; any hypothesis drawn before this must be thoroughly qualified and hedged in the interests of scientific accuracy.

In project organizations, the analytical mind produces the concepts by which the project advances toward its goal. But without the integrative function, often nothing would be done with the concepts originating in the analytical function. A project manager must be capable of both integration and analysis, and must understand that the rigorous training of professional technologists with its emphasis upon analysis sometimes impairs their integrative ability.

THE ADVANCED-TECHNOLOGY FUTURE

J. Sterling Livingston, Professor of Business Administration at the Harvard Business School, opened a recent essay with these significant words, "The most critical question facing the United States today is how it can regain undisputed technological leadership . . ." The character of American technological advancement during the next five years will shape our future and determine our survival or extinction.

The role to be played by project management in these years ahead will be challenging, exciting, and crucial. Truly it will be the acid test of the project manager and the project concept, but it will be more than that: It will be a momentous trial of free enterprise, business administration, and progressive industrial management as we know them today.



—Official U.S. Navy photograph

A hunter-killer anti-submarine warfare task group is shown in this view of a part of Task Force Alfa. This group comprises seven destroyers, two submarines, and ASW aircraft carrier and air support units.

K. KAFALI

INTERACTION BETWEEN SINGLE SCREW PROPELLERS AND TWIN RUDDERS PLACED SYMMETRICALLY IN THE SCREW RACE

THE AUTHOR

studied naval architecture at the Department of Naval Architecture Mechanical Engineering Faculty of the Technical University of Istanbul. Graduated in 1948 and has become an Assistant Professor at the Department of Naval Architecture, Technical University of Istanbul since 1953. His work is connected generally with problems of theoretical naval architecture. At the time of writing this paper Professor Kafali was a guest at the Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology. It was there that he conducted the research on which the paper is based.

The research in this paper was done with appointment supported by the I.C.A. under a program administered by the National Academy of Sciences.

SYNOPSIS

This paper deals with experiments on the interaction problem of twin rudders and single screw propellers. The research includes only rudders which were placed just behind the propeller with the zero angle of attack, and set symmetrically relative to the propeller axis.

Some particular locations of twin rudders have shown an appreciable improvement in the propeller efficiency and also in the propeller thrust. For the ships which need twin rudders to obtain high steering reliability, the location of rudders relative to the propeller seems to be an important factor, not only for the characteristics of control surfaces, but also for the characteristics of propellers.

INTRODUCTION

The literature on naval architecture gives us many examples where multi-rudders have been used on different types of ships. These rudders generally have been designed to improve the steering and course-keeping qualities of ships. Tugboats and barges encounter some deficiency in maneuvering, especially in shallow water. To overcome this difficulty, it has been common practice to use multi-rudders. If the screw races of a twin screw ship are far from the centerline, a single rudder placed between the propellers does not swing into them even at large rudder angles. In this case, twin rudders, each placed in the race of the individual propeller, would produce much better steering efficiency. This

A hunter-killer anti-submarine warfare task group is shown in this view of a part of [illegible] ASW aircraft carrier and air support units.

NOMENCLATURE

a	Gap between rudders, in feet. Figure 4
b	Longitudinal distance between rudder's leading edge and propeller's hub edge, in feet. Figure 4
D	Diameter of propeller, in feet.
P	Pitch of propeller.
B.T.F.	Blade thickness fraction.
z	Number of blades of propeller.
R.P.M.	Revolution per minute of propeller.
M.W.R.	Mean width ratio.
K_T	Thrust coefficient $\frac{T}{\rho n^2 D^4}$.
T	Thrust of propeller, in pounds.
n	Revolution per second of propeller.
K_Q	Torque coefficient $\frac{Q}{\rho n^2 D^5}$.
Q	Torque of propeller, in foot-pounds.
e_p	Efficiency of propeller $\frac{J}{2\pi} \cdot \frac{KT}{K_Q}$.
J	Advance speed coefficient $\frac{v}{n D}$
v	Speed of propeller, in foot-seconds.
ρ	Density of water.

type of installation is commonly used on different kinds of ships.[1, 3]

These rudders are generally located slightly to one side of the propeller shaft line in order to minimize noise and vibration. Moreover, this permits shaft withdrawal without removal of the rudders. Published research on the location of rudders which are offset from the shaft line is very scarce.[2]

If improved steering qualities are needed in the case of a single-screw design, twin rudders might be desirable. This would also avoid the problem of erosion of a single rudder located in the hub vortex of the propeller.

Therefore, it would be reasonable to look for an optimal location for rudders which would provide improved steering and, in addition, improve the propulsive coefficient.

Two typical examples of this type of installation are given in Figure 1 for the Turkish car ferry, *Kartal*, and the other in Figure 2, U.S.N. ocean escort, *Dealey*. The car ferry is propelled by a three-

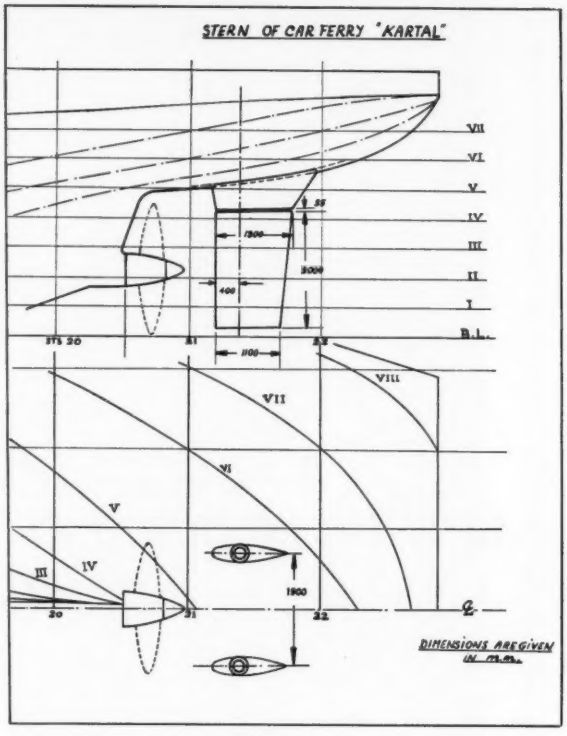


Figure 1.

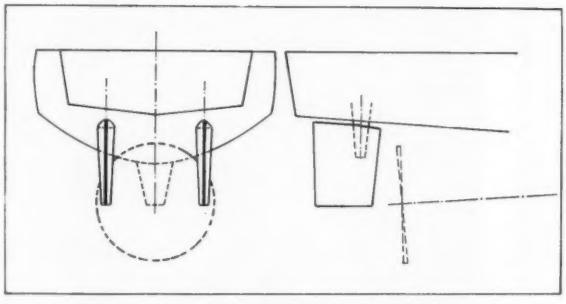


Figure 2.

bladed propeller and the latter has a five-bladed propeller.

In both cases, the twin rudders are placed in the race of the propeller. The main reason in both cases was to improve the maneuvering qualities rather than to obtain an improved propulsive efficiency.

Another type of twin rudders-single screw design can be seen in Reference 4. However, in this case twin rudders were selected for a different design reason than considered in this paper.

DESCRIPTION OF EXPERIMENTS

The main scope of this research, as mentioned before, was to find an optimal location for twin rudders relative to the propeller,

a) from the propulsive point of view, and
b) from the steering point of view.

This paper deals only with question (a).

For this purpose, the Cavitation Tunnel, of the Massachusetts Institute of Technology, a description of which is given in Reference 5, has been used as a circulating water channel.

Through the upper opening of the tunnel two rudders were placed on bar frames as shown in Figure 3, in such a way that the gap between rud-

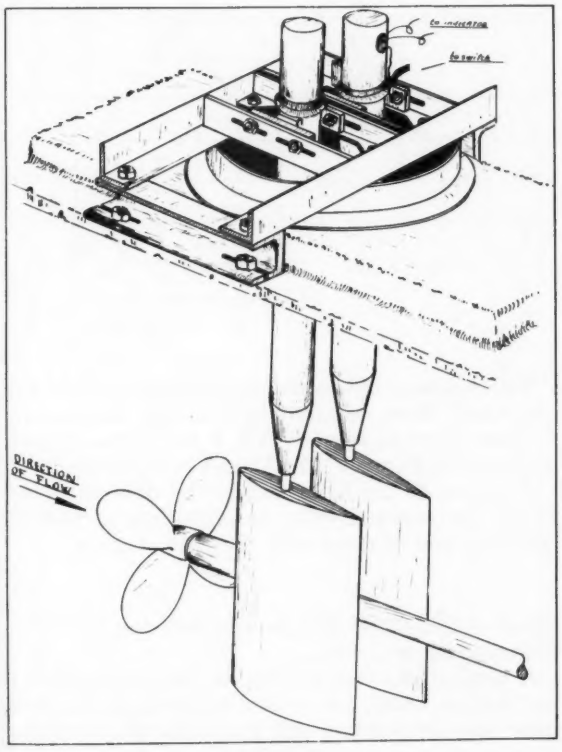


Figure 3.

ders and also the distance of the rudders from a fixed point on the propeller could be changed by moving the rudders transversely and longitudinally on the frames. In spite of the small radius of the tunnel, in that limited area, four different gaps and three different distances were selected. One of the rudders was equipped with a strain gage dynamometer which gives us the forces when the rudder is in action. Details of this type of dynamometer may be seen in Reference 6.

The dimensions of two cast bronze rudders, which are symmetrical airfoil sections, are given in Table I and in Figure 4.

TABLE I

Length of chord	6	inches
Height of rudder	10	inches
Location of maximum thickness from leading edge	2	inches
Maximum thickness of upper section	0.76	inch
Maximum thickness of lower section	0.70	inch
Stock center from leading edge	2	inches

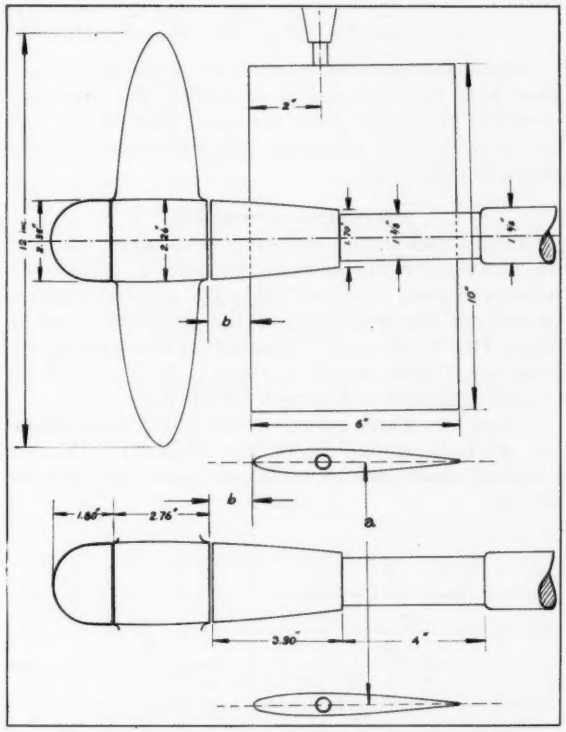


Figure 4.

Geometrical characteristics and dimensions of the two different propellers which were tested with the zero angle of attack of the rudders are given in Table II.

TABLE II

	Propeller A	Propeller B
D	12 inches	12 inches
P/D	1.000	0.795
M.W.R	0.248	0.248
B.T.F.	0.05	0.05
Rake	none	none
Number of Blades	4	4
R.P.M.*	540	780
Type of Section	airfoil	airfoil
Material	aluminum	bronze

*To avoid excessive forces on the strain gages, the propeller R.P.M. had to be lower than in the usual routine work of the Cavitation Tunnel.

All experiments of this research have been carried out according to a program of systematical variations of rudder locations relative to the propeller. This program is given in Table III.

TABLE III—*Number of Program*

Longitudinal Distance from Propeller Hub's Edge, in inches	Propeller A				Propeller B			
	Gap Between Rudders in inches				Gap Between Rudders in inches			
	7.1	8.3	10.25	12.2	7.1	8.3	10.25	12.0
0	01	02	03	04	01	02	03	04
1	11	12	13	14	11	12	13	14
2	21	22	23	24	21	2	23	24

During the tests the water level of the tunnel had been kept constant and it was taken 2.8 times the propeller diameter, from the shaft line of the tunnel. Atmospheric pressure was maintained at the water surface.

DISCUSSION OF RESULTS *

Torque and thrust measurements were made in the tunnel for the selected propellers (whose dimensions were given in Table II) without rudders present at the beginning of the program given in Table III. These were repeated at the end of the program. These results are given in Figure 5 for Propeller A and in Figure 6 for Propeller B.

About ten water speeds were found satisfactory for the reduced R.P.M. of the propellers. The top value of speed had to be taken below ten feet per second.

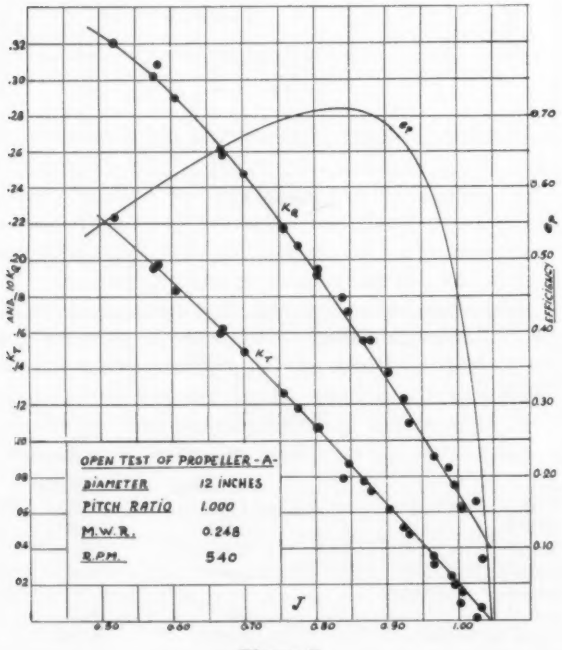


Figure 5.

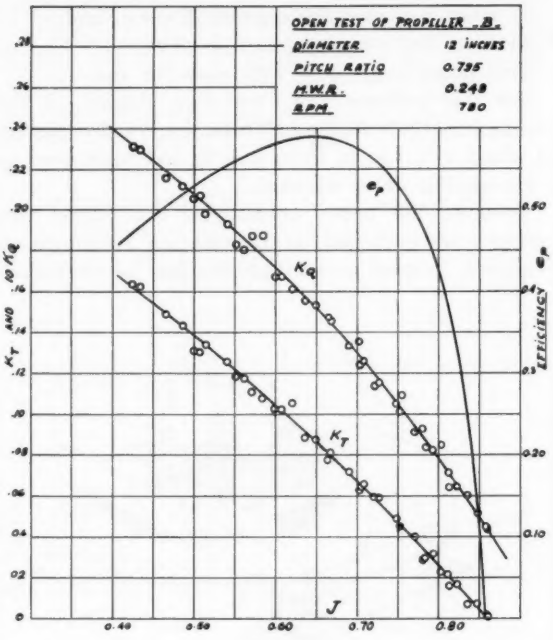


Figure 6.

The results of individual experiments for four gap ratios and three different longitudinal distance ratios are given in Figures 7, 8, 9 and 10 for Propeller A and in Figure 11, 12, 13 and 14 for Propeller B.

A glance at the figure shows the differences between the characteristics of propellers in isolated condition and of those with the twin rudders.

Effect of Gap Ratio a/D on the Propeller Characteristics

A general study of the figures shows clearly that for rudders which are located in the propeller race, some improvement of the propeller efficiency and thrust could be expected. In the case of a smaller gap between the rudders and the propeller shaft line, the results become somewhat questionable due to experimental error in the region of very small gaps. With the rudders located in the outer part of propeller race, the thrust and efficiency are diminished. With the rudders located beyond the screw race, generally an improvement of thrust and efficiency can not be expected.

The improvement of thrust increases with increasing **J** values. At the lower values of **J**, the amount of improvement which is taken as a percentage of the difference in thrust with and without rudders does not seem appreciable; but in the possible working range of the propeller this amount is important enough to be taken into consideration.

In the case of rudders placed beyond propeller race, the results seem contrary to the above facts.

* It was not necessary to make any corrections to the results for wall effect, distribution of tunnel velocities, etc.

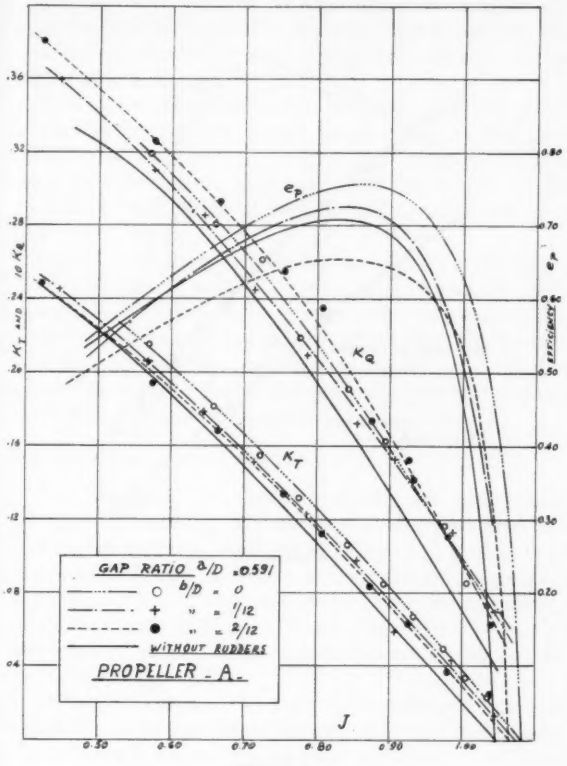


Figure 7.

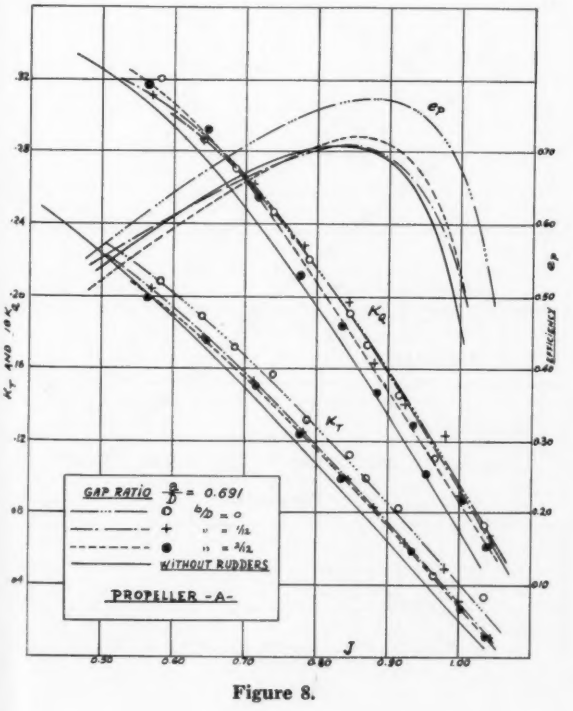


Figure 8.

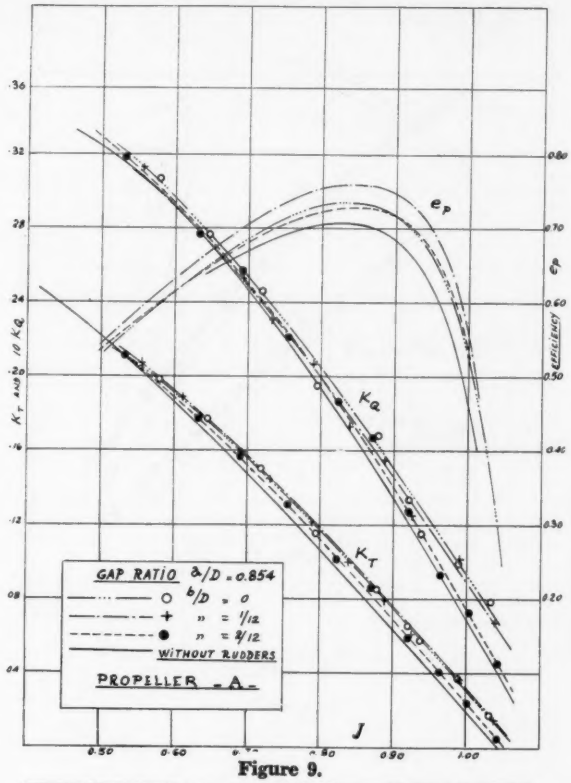


Figure 9.

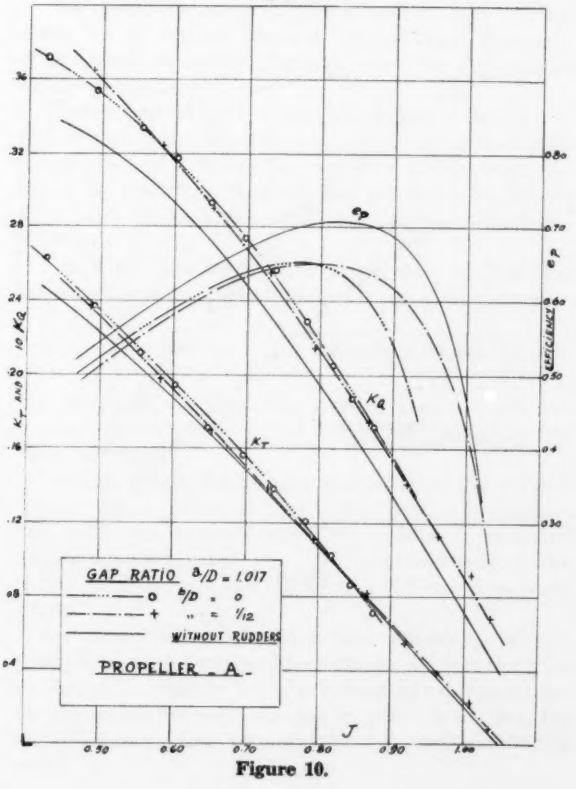


Figure 10.

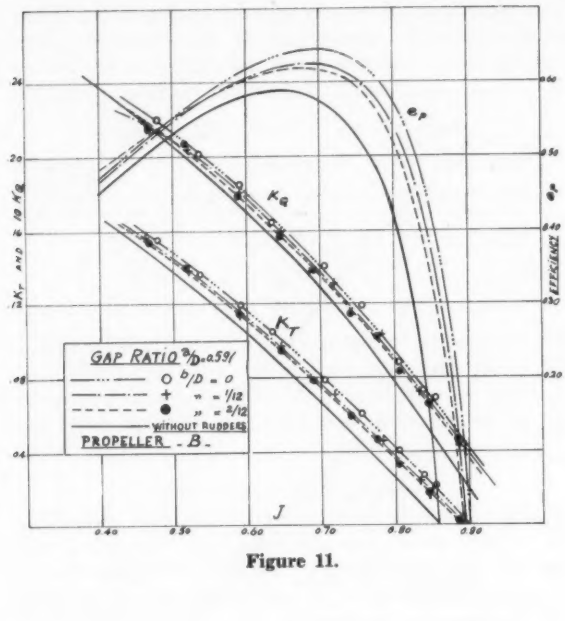


Figure 11.

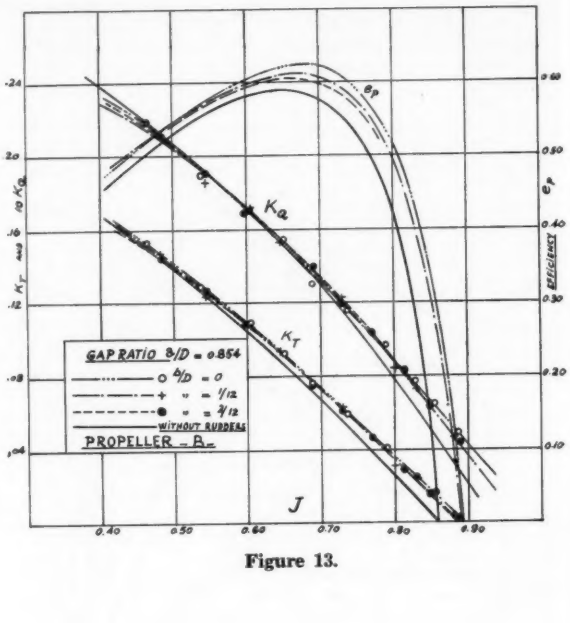


Figure 13.

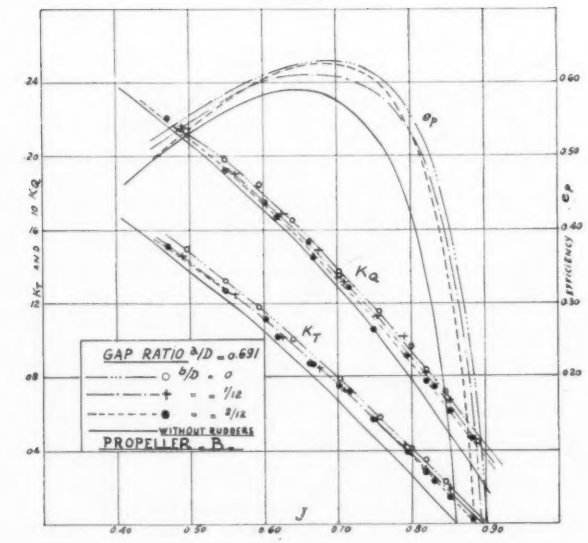


Figure 12.

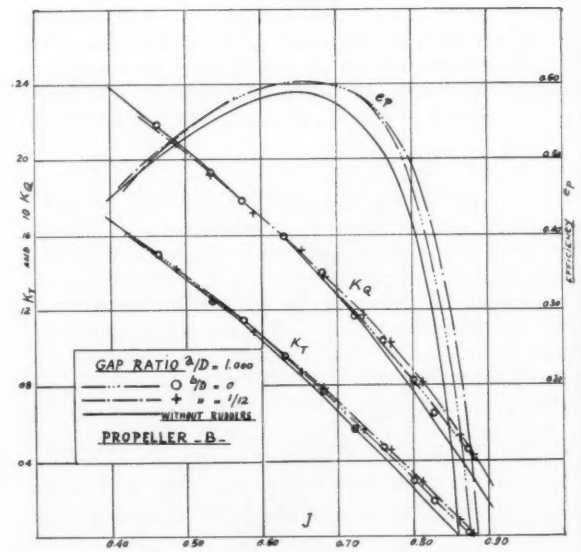


Figure 14.

As a matter of fact, in the higher **J** values, and especially in the working range of the propeller, the change in thrust is not significant enough to be taken into account.

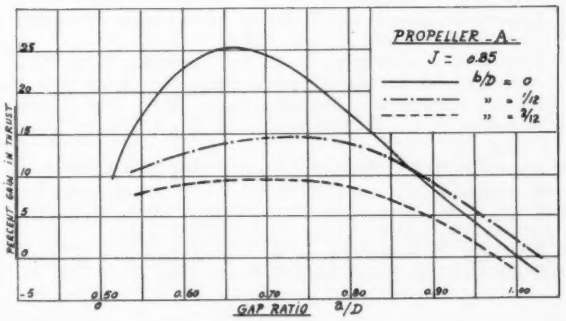
The same observation can be made regarding the propeller having the lower pitch ratio. In this propeller the extreme gap ratio had been chosen as 1.00. In this case of gap ratio 1.00 an improvement in thrust still exists at high **J** values although it is not very great.

Similar statements can be said for the efficiency of Propellers A and B. In fact, with the twin rudders placed in the outer parts of the propeller race, there is not as large a gain in efficiency. The condition of rudders located in the inner parts of the propeller race offer somewhat higher efficiencies than those of the outer parts.

Optimal Location of Rudders

By means of the figures mentioned previously, the general survey can be summarized to give the optimal location of rudders which are placed behind Propellers A and B. This has been done in a graphical manner and given in Figure 15 for improvement of thrusts and in Figure 16 for the improvement of efficiencies. A favorable selection can be picked by using these figures.

In the vicinity of the maximum efficiency, a reasonable range has been chosen and the differences in per cent between the thrusts of propeller without rudders and the thrusts with rudders have been replotted on a basis of gap ratio, a/D, by taking the distance ratios, b/D, as a parameter.



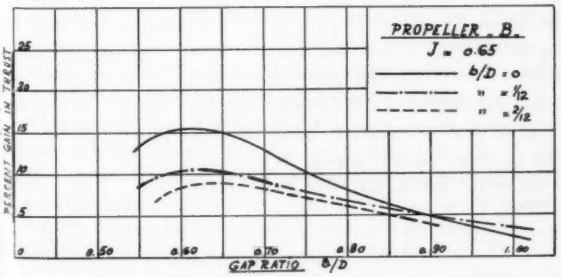
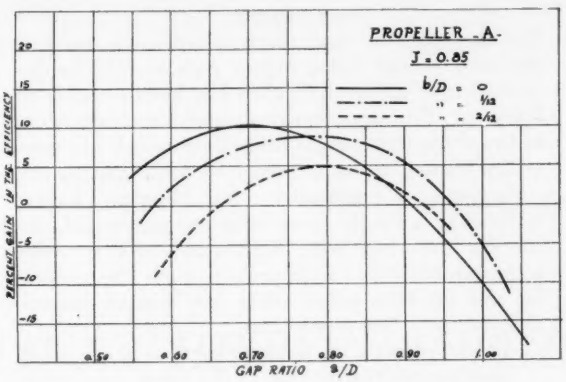


Figure 15.



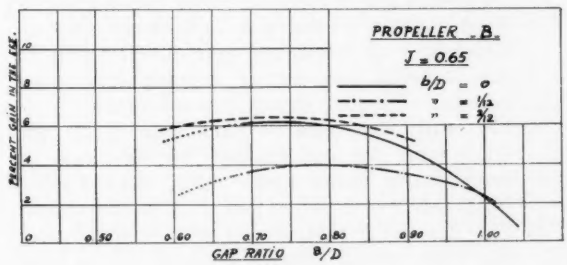


Figure 16.

The extreme parts of the propeller race do not seem an adequate location for rudders from the thrust and efficiency point of view in the case of either propeller.

Therefore, without considering other factors in the design (e.g. vibration, noise, constructive complications, etc.), it can be said that the shortest distance between the rudders and propeller surface is most advantageous for obtaining a higher thrust and efficiency.

For the propeller with a pitch ratio of 1.00, the improvement in thrust amounts to about twenty-five per cent for $a=\frac{2}{3}$ the diameter of the propeller and b/D=0. For this rudder location, an improvement in efficiency of about ten per cent has been obtained.

Similar results have been reached for the propeller having a pitch ratio of 0.795. In this condition, and with the same location of rudders mentioned above, about sixteen per cent improvement of the thrust and six per cent gain of efficiency has been found.

An examination of thrust and efficiency of two propellers with twin rudders shows us that the gain in thrust is greater for the higher pitch ratio than for the propeller with the lower pitch ratio. But, for the efficiency, this consideration is not so strictly valid.

CONCLUSION

1. The progress in machinery design has reached the point where much higher powers may be delivered to a single shaft than has been possible in the past. This opportunity attracts our attention to the ships with single propellers which are generally known to be superior to multi-propellers.

   As far as the propulsive and steering characteristics of a single screw ship are concerned, designing the ship with twin rudders may offer some possibilities for improving both the propeller and rudders when these are located reasonably far into the screw race.

   a) In the design of a single screw ship which needs more thrust and, at the same time, more maneuverability, making use of twin rudders located in the propeller race, if these appendages conform to the ship lines, may offer an advantage of reliability and effectiveness in the steering and course keeping and some amount of higher thrust and efficiency.

   b) Generally, it would be advantageous for the ships with flat and transom sterns (such as ferry boats, some navy ships, tugs, fishing boats, etc.) to be equipped with twin rudders.

   c) For the owner who would be concerned over the high cost of nozzles, making use of twin rudders placed behind a single screw, would be another way to obtain a sufficient improvement in propulsive efficiency and thrust. Also, much better rudders characteristics would be expected.

   d) Another advantage of the twin rudders-single screw system is that the noise and vibration due to the interaction of rudders and propeller would be lower than for a single screw-single rudder system. Furthermore, erosion of rudders due to the impinging of the vortex shed of the single screw can be eliminated by using twin rudders.

2. Although the pitch ratio, disc area ratio, aspect ratio, thickness ratio, shape, etc., of rudders and propeller affect characteristics of both propulsion and steering, if the design permits the rudders to be located

   a) at $\frac{b}{D} = 0$, the gap between rudders should be chosen within 0.65-0.70 of the diameter of the propeller.

   b) at $\frac{b}{D} = \frac{1}{12}$ and $\frac{2}{12}$, the favorable gap ratios lie within 0.75-0.80 of the diameter of the propeller.

3. Further research on this subject is necessary for the condition of twin rudders-single screw located behind models tested in a towing tank or circulating channel. Moreover, different propeller and rudder parameters, such as pitch ratios, D.A.R., number of blades, aspect ratio, thickness ratio, etc., would have to be considered in such a research program.

ACKNOWLEDGEMENTS

The author would like to extend his thanks to Professor L. Troost, Head of the Department of Naval Architecture and Marine Engineering of the Massachusetts Institute of Technology and to Professor S. C. Powell, Director of the Cavitation Tunnel, for their interest and helpful assistance with regard to this research.

The author is also indebted to Messrs. J. E. Kerwin, N. A. Brown and R. Johnson, for their assistance in the preparation of the instruments and the paper.

BIBLIOGRAPHY

1. Lammeren, Troost and Koening; "Resistance, Propulsion and Steering of Ships"; page 319.
2. Downs, B. H., Swayne, G. B. and Henning, R. E.; "Investigation of Rudder Characteristics with Variations of Rudder Position in a Propeller Race"; M.I.T. Thesis, 1950.
3. Saunders, H. E., "Hydrodynamics in Ship Design," Volume I, page 579.
4. Saunders, H. E., "Hydrodynamics in Ship Design," Volume II, page 521.
5. Lewis, F. M., "Propeller Testing Tunnel at the Massachusetts Institute of Technology," S.N.A.M.E., 1939.
6. Kissinger, R. and Roop, L. A., "Development of a Model Rudder Dynamometer," M.I.T. Thesis, 1943.

A new design RCA electronic tube has been named the Nuvistor tube. Thimble-sized, it is made chiefly of steel, molybdenum, tungsten and ceramic, containing no mica or glass. The tube can withstand impact loads of 850g and can operate in a range of minus 320 degrees Fahrenheit to 660 degrees Fahrenheit. Designed for a wide variety of purposes, both military and commercial, it requires less power than conventional types.

—from COMPUTER AND AUTOMATION
July, 1959

TETSUO NISHIYAMA

LIFTING-LINE THEORY OF THE SUBMERGED HYDROFOIL OF FINITE SPAN

THE AUTHOR

studied Naval Architecture mainly at the Department of Naval Architecture of Tokyo University, Tokyo, Japan from 1944-47. After several post-graduate courses, he has become an Assistant Professor in the Department of Mechanical Engineering of Tohoku University in Sendai. His work is connected with general hydromechanical problems in Naval Architecture, in particular with wave resistance theory and with the submerged hydrofoil.

PART II
Hydrodynamical Characteristics of the Submerged Hydrofoil of Dihedral Angle

INTRODUCTION

From the viewpoint of direct application to practical problems, the theory of the submerged hydrofoil of dihedral angle is of extreme importance. Up to date some theoretical treatments of the submerged hydrofoil of dihedral angle as a three dimensional hydrodynamical problem have been published. These researches were worked out by Tinney and Kaplan; the former [1] introduces an empirical formula for the lift and examines the wave resistance analytically by a rather rough method, and the latter [2] treats of wave patterns and wave resistance. However we cannot find in either paper any consideration of the circulation itself.

Generally the lift is proportional to the circulation and the wave resistance to the square of the circulation. Hence in order to examine the lift and wave resistance, it is of primary importance to obtain the circulation over the span as precisely as possible, taking the existence of the free water surface into account. It is in this area that improvements still need to be made.

Because of a fairly large aspect ratio and small loading, Prandtl's original concept of the lifting-line may be applied to the submerged hydrofoil of dihedral angle. Therefore in this paper a calculating method is proposed for obtaining the hydrodynamical characteristics of the submerged hydrofoil of dihedral angle from the standpoint of the lifting-line theory.

VELOCITY POTENTIAL

We take the origin of co-ordinate 0 on the still water level with x-axis in the direction of advance, y-axis laterally sideward and z-axis vertically upward. Furthermore the ordinate η is taken in the direction of span, the dihedral angle of which is denoted by β, as shown in Figure 1.

Applying the concept of the lifting-line, the hydrofoil can be replaced by a bound vortex, namely lifting-line, and the free vortex may be considered as being situated on the plane parallel to the direction of advance through the bound vortex.

When a hydrofoil of dihedral angle and of half

span b/2 advances in an infinite fluid with the constant velocity C at the distance f from the origin, the velocity potential is given by ϕ_∞. After some reduction:

$$\phi_\infty = \mathrm{Re}\Big| -\frac{m}{8\pi^2}\, i \left[\int_{-\frac{b}{2}}^{\frac{b}{2}} \Gamma(\eta)\,d\eta \int_{-\pi}^{\pi} \sec\theta\, d\theta \int_0^\infty e^{-K(z+f-|\eta|l)+iK\tilde{w}}\, dK \right.$$

$$\left. -2\pi i \int_{-\frac{b}{2}}^{\frac{b}{2}} \Gamma(\eta)\,d\eta \int_0^\infty e^{-u(z+f-|\eta|l)} \cos u(y-\eta m)\, du \right]$$

$$\pm \frac{l}{8\pi^2}\left[\left(\int_{-\frac{b}{2}}^{0} \right) \Gamma(\eta)\,d\eta \int_{-\pi}^{\pi} \tan\theta\, d\theta \int_0^\infty e^{-K(z+f-|\eta|l)+iK\tilde{w}}\, dK \right.$$

$$\left. +2\pi \left(\int_{-\frac{b}{2}}^{0} \right) \Gamma(\eta)\,d\eta \int_0^\infty e^{-u(z+f-|\eta|l)} \sin u(y-\eta m)\, du \right] \Big| \qquad \cdots\cdots (1)$$

where

$$\tilde{w} = x\cos\theta + (y-\eta m)\sin\theta$$

$$l = \sin\beta, \quad m = \cos\beta$$

In the third and fourth terms we should take the upper and lower terms correspondingly to the positive and negative signs respectively. As the second and fourth terms do not include the variable **x**, it may be interpreted that the first and third terms represent the fluid motion by the bound vortex and the second and fourth terms the fluid motion by the free vortex.

When we denote the velocity potential of the submerged hydrofoil ϕ, the boundary condition on the free water surface can be given by:

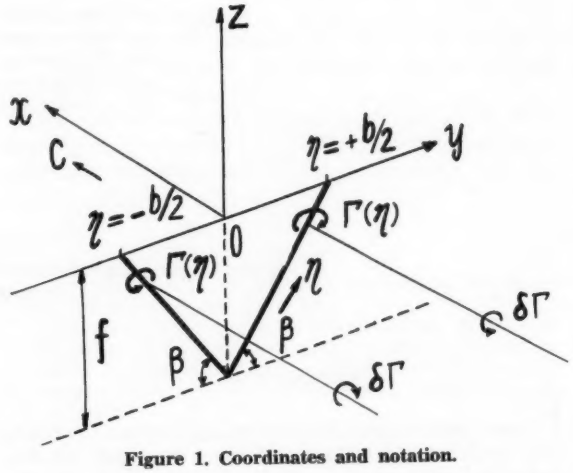


Figure 1. Coordinates and notation.

$$\frac{\partial^2\phi}{\partial x^2} + K_0 \frac{\partial\phi}{\partial z} - \mu \frac{\partial\phi}{\partial x} = 0 \quad \text{at } z=0 \qquad \cdots\cdots (2)$$

where

$$K_0 = g/C^2$$

Then from (1) and (2) the velocity potential can be expressed in the form:

$$\phi = \phi_\infty + \phi_1 + \phi_2 \qquad \cdots\cdots (3)$$

$$\phi_1 = \mathrm{Re}\Big| -\frac{m}{8\pi^2}\, i \left[-\int_{-\frac{b}{2}}^{\frac{b}{2}} \Gamma(\eta)\, d\eta \int_{-\pi}^{\pi} \sec\theta\, d\theta \int_0^\infty e^{-K(f-|\eta|l-z)+iK\tilde{w}}\, dK \right.$$

$$\left. -2\pi i \int_{-\frac{b}{2}}^{\frac{b}{2}} \Gamma(\eta)\, d\eta \int_0^\infty e^{-u(f-|\eta|l-z)} \cos u(y-\eta m)\, du \right]$$

$$\pm\frac{1}{8\pi^2}\Bigg[-\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\Gamma(\eta)\,d\eta\int_{-\pi}^{\pi}\tan\theta\,d\theta\int_0^{\infty}e^{-K(f-|\eta|l-z)+iK\tilde{w}}dK$$

$$+2\pi\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\Gamma(\eta)\,d\eta\int_0^{\infty}e^{-u(f-|\eta|l-z)}\sin u(y-\eta m)\,du\Bigg]\Bigg| \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\phi_2=\mathrm{Re}\Bigg|\frac{m}{4\pi^2}\,iK_0\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec^3\theta\,d\theta\int_0^{\infty}\frac{e^{-K(f-|\eta|l-z)+iK\tilde{w}}}{K-K_0\sec^2\theta+i\mu\sec\theta}\,dK$$

$$\mp\frac{l}{4\pi_2}\,K_0\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\Gamma(\eta)d\eta\int_{-\pi}^{\pi}\sec^3\theta\sin\theta\,d\theta\int_0^{\infty}\frac{e^{-K(f-|\eta|l-z)+iK\tilde{w}}}{K-K_0\sec^2\theta+i\mu\sec\theta}dK\Bigg| \ldots\ldots (5)$$

where the Rayleigh's viscosity coefficient μ is to be set equal to zero after serving its purpose.

The velocity potential ϕ_1 is the image of ϕ_∞ when the free surface is conceived as a fixed boundary; the first and third terms represent the fluid motion by the bound vortex at the image point, and the second and fourth terms the fluid motion by the free vortex at the image point. The velocity potential ϕ_2 represents the wave disturbance.

Now transforming ϕ_2 by the contour integration and paying special attention to the vicinity of the hydrofoil, we have this relation at extremely high speeds:

$$\lim_{\substack{x\to 0\\ K_0\to 0}}[\phi_2]_{\mathrm{wave}}=\frac{m}{2\pi}\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)d\eta\int_0^{\infty}e^{-u(f-|\eta|l-z)}\cos u(y-\eta m)\,du$$

$$\mp\frac{l}{2\pi}\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\Gamma(\eta)d\eta\int_0^{\infty}e^{-u(f-|\eta|l-z)}\sin u(y-\eta m)\,du \ldots\ldots\ldots\ldots (6)$$

Comparing (6) with (4), we have

$$\lim_{\substack{x\to 0\\ K_0\to 0}}[\phi_2]_{\mathrm{wave}}=-2\times(\text{the 2nd and 4th terms of }\phi_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6')$$

From (6′) we can see that the velocity potential of the regular wave is equal to twice that of the image free vortex at extremely high speeds; in other words the wave motion just after the hydrofoil approaches gradually to the free vortex motion as the speed becomes higher. The relation (6′) can be used to consider the relation between the induced and wave resistances and the variation of the wave resistance with the aspect ratio.

INDUCED VELOCITY

Now we confine our attention to the induced velocity normal to the span. Differentiating normally to the span and evaluating the integral after altering the variable of the integration, we have

$$w=-\frac{m^2}{4\pi}\int_{-\frac{b}{2}}^{\frac{b}{2}}\frac{\Gamma(\eta)}{(y-\eta m)^2}d\eta\mp\frac{l^2}{4\pi}\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\frac{\Gamma(\eta)}{(y-\eta m)}\,d\eta$$

$$+\frac{m^2}{4\pi}\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)\overline{K}_H(y-\eta m,\ f-|\eta|l)d\eta$$

$$+\frac{lm}{4\pi}\int_{-\frac{b}{2}}^{0}\Gamma(\eta)\overline{K}_{HV}(y-\eta m,\ f-|\eta|l)d\eta$$

$$\pm\frac{l^2}{4\pi}\left(\int_0^{\frac{b}{2}}+\int_{-\frac{b}{2}}^{0}\right)\Gamma(\eta)\overline{K}_V(y-\eta m,\ f-|\eta|l)d\eta \ldots\ldots (7)$$

where

$$\underline{\overline{K}}_H=\frac{-4(f-|\eta|l)^2+(y-\eta m)^2}{\{4(f-|\eta|l)^2+(y-\eta m)^2\}^2}+\frac{K_0^2}{2}e^{-K_0(f-|\eta|l)}\left[\left\{1+\frac{4(f-|\eta|l)^2}{4(f-|\eta|l)^2+(y-\eta m)^2}\right\}\underline{\overline{K}}_0\right.$$

$$\left.+2\left\{\frac{2(f-|\eta|l)}{\sqrt{(y-\eta m)^2+4(f-|\eta|l)^2}}-\frac{1}{K_0\sqrt{(y-\eta m)^2+4(f-|\eta|l)^2}}+\frac{8(f-|\eta|l)^2}{K_0\{(y-\eta m)^2+4(f-|\eta|l)^2\}^{3/2}}\right\}\underline{\overline{K}}_1\right] \quad \ldots\ldots (8)$$

$$\underline{\overline{K}}_{HV}=-2\frac{4(f-|\eta|l)(y-\eta m)}{\{4(f-|\eta|l)^2+(y-\eta m)^2\}^2}+\frac{4K_0^2e^{-K_0(f-|\eta|l)}(y-\eta m)}{\sqrt{(y-\eta m)^2+4(f-|\eta|l)^2}}\left[\left\{\frac{1}{4}\right.\right.$$

$$\left.\left.+\frac{f-|\eta|l}{K_0\{(y-\eta m)^2+4(f-|\eta|l)^2\}}\right\}\underline{\overline{K}}_1+\frac{f-|\eta|l}{4\sqrt{(y-\eta m)^2+4(f-|\eta|l)^2}}(\underline{\overline{K}}_0+\underline{\overline{K}}_1)\right] \quad \ldots\ldots (9)$$

$$\underline{\overline{K}}_V=\frac{-4(f-|\eta|l)^2+(y-\eta m)^2}{\{4(f-|\eta|l)^2+(y-\eta m)^2\}^2}+K_0^2e^{-K_0(f-|\eta|l)}\left[\frac{4(f-|\eta|l)^2}{K_0\{(y-\eta m)^2+4(f-|\eta|l)^2\}^{3/2}}\underline{K}_1\right.$$

$$\left.-\frac{(y-\eta m)^2}{4\{(y-\eta m)^2+4(f-|\eta|l)^2\}}(\underline{\overline{K}}_0+\underline{\overline{K}}_2)\right] \quad \ldots\ldots (10)$$

where $\underline{\overline{K}}_0$, $\underline{\overline{K}}_1$ and $\underline{\overline{K}}_2$ are modified Bessel functions of the 2nd kind, the arguments of which are:

$$\tfrac{1}{2}K_0\{(y-\eta m)^2+4(f-|\eta|l)^2\}^{\frac{1}{2}}$$

The terms below the 3rd in (7) are the additive terms due to the existence of the free surface. Taking the limiting case, we have:

$$\lim_{K_0\to 0}[\text{the terms below the 3rd in (7)}]$$
$$=-\lim_{K_0\to\infty}[\text{the terms below the 3rd in (7)}] \quad \ldots\ldots (11)$$

Therefore the induced velocity normal to the span decreases at extremely low speeds and increases at extremely high speeds. Corresponding to this, the effective angle of attack increases at extremely low speeds and decreases at extremely high speeds.

INTEGRAL EQUATION AND ITS NUMERICAL SOLUTION

The circulation on the span of the submerged hydrofoil is given by:

$$\Gamma(y)=\frac{m_0}{2}t(y)C\left\{\alpha(y)-\frac{w(y)}{C}\right\};\ m_0=2\pi w \quad \ldots\ldots (12)$$

On the other hand the circulation in an infinite fluid is given by:

$$\Gamma_\infty(y)=\frac{m_0}{2}t(y)C\left\{\alpha(y)-\frac{w_\infty(y)}{C}\right\} \quad \ldots\ldots (13)$$

Taking a fairly large aspect ratio and small loading into account, the 2nd order term may be neglected. Therefore, from (7), (12) and (13) we obtain:

$$\Gamma(y)=-\frac{m_0}{8\pi}t(y)\left[m^2\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)\underline{\overline{K}}_H(y-\eta m,\ f-|\eta|l)d\eta\right.$$

$$+lm\int_{-\frac{b}{2}}^{0}\Gamma(\eta)\underline{\overline{K}}_{HV}(y-\eta m,\ f-|\eta|l)d\eta$$

$$\pm l^2\left(\int_{0}^{\frac{b}{2}}_{\int_{-\frac{b}{2}}^{0}}\right)\Gamma(\eta)\underline{\overline{K}}_V(y-\eta m,\ f-|\eta|l)d\eta$$

$$\left.+\Gamma_\infty(y)\right] \quad \ldots\ldots (14)$$

(14) may be regarded as an integral equation with respect to $\Gamma(y)$. When the circulation in an infinite fluid is given, the corresponding value in the submerged condition can be found by solving this integral equation.

However an analytical solution for this integral equation is too troublesome to obtain. And so, from

the fact that (14) is of Fredholms' type of the second kind and the kernal $\overline{K}_H(y-\eta m,\ f-|\eta|l)$ etc. are regular, we can solve numerically by applying the Nyström's method.

Hence, putting

$$\Gamma(y)=2bC\,\gamma(y),\ \Gamma_\infty(y)=2bC\,\gamma_\infty(y) \quad \ldots\ldots (15)$$

(14) can be reduced to

$$\gamma(y)=-\frac{m_0}{16\pi b}t(y_j)\Big[2m^2\sum_1^n a_i^n\,\gamma(\eta_i)\overline{K}_H\ (y_j-\eta_i m,\ f-|\eta_i|l)$$
$$+lm\sum_1^n a_i^n\,\gamma(\eta_i)\overline{K}_{HV}\ (y_j-\eta_i m,\ f-|\eta_i|l)$$
$$\pm l^2\sum_1^n a_i^n\,\gamma(\eta_i)\overline{K}_V\ (y_j-\eta_i m,\ f-|\eta_i|l)\Big]$$
$$+\gamma_\infty(y_j) \quad \ldots\ldots (14')$$

Taking seven points over the span, seven simultaneous equations are obtained, but we can reduce them to four simultaneous equations owing to the symmetry of the distribution of the circulation. The coordinates and coefficients in the numerical calculation are as follows:

$$\begin{pmatrix}\eta_1\\ \eta_2\end{pmatrix}=\overline{+}0.94910 \qquad \begin{pmatrix}a_1^7\\ a_7^7\end{pmatrix}=0.06474$$
$$\begin{pmatrix}\eta_2\\ \eta_6\end{pmatrix}=\overline{+}0.74153 \qquad \begin{pmatrix}a_2^7\\ a_6^7\end{pmatrix}=0.13985 \quad \ldots\ldots (16)$$
$$\begin{pmatrix}\eta_3\\ \eta_5\end{pmatrix}=\overline{+}0.40584 \qquad \begin{pmatrix}a_3^7\\ a_5^7\end{pmatrix}=0.19091$$
$$\eta_4=0 \qquad a_4^7=0.20898$$

Thus, as the circulation can be obtained by that procedure, the lift and resistance can be calculated respectively by:

$$L=l\rho C\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)d\eta \quad \ldots\ldots (17)$$

$$D=\rho\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)w(\eta)d\eta \quad \ldots\ldots (18)$$

Generally the 2nd order term becomes more or less large at the tip corresponding to the surface-piercing point and its vicinity, and then the accuracy of the approximation deteriorates. However the absolute value of circulation is very small at the tip, and so it may be considered that there is no decisive effect on the lift and resistance.

NUMERICAL EXAMPLES

Numerical calculations are carried out for the following conditions:

aspect ratio	$\lambda=8$
dihedral angle	$\beta=30°$
chord length	$t/t_{y=0}=1.0$
immersion	$f/t_{y=0}=2.0$

These data [3] were taken from the existing hydrofoil of dihedral angle. The distribution of the effective circulation over the span is shown in Figure 2;

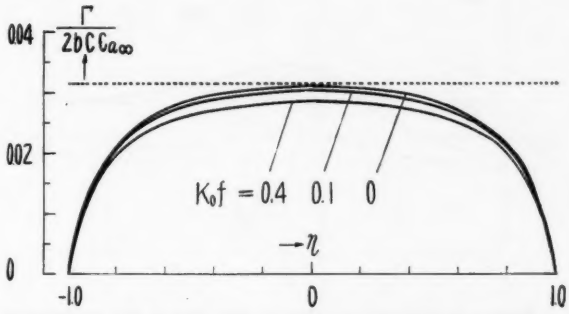


Figure 2. Distribution of the effective circulation. (Dotted line shows the corresponding value in an infinite fluid.)

since the dotted line shows the corresponding distribution of circulation in an infinite fluid, the difference between both lines, full and dotted, may be regarded as being caused by the effect of the free surface. Its amount is the largest at the tip which is just at the free surface itself.

The lift is shown in Figure 3; comparing with the corresponding value for the horizontal hydrofoil shown by the dotted line, we can see the effect of a dihedral angle on the lift. It can be safely said that the effect of the free surface becomes more predominant as the dihedral angle is larger and consequently the lift decreases. Further the lift at extremely high speeds approaches the limiting value which is given by 0.88 $C_{a\infty}$ by this present method. On the other hand Tinney's empirical formula

$$C_a/C_{a\infty}=1-0.422\,e^{-1.454\frac{f_m}{t}} \quad \ldots\ldots (19)$$

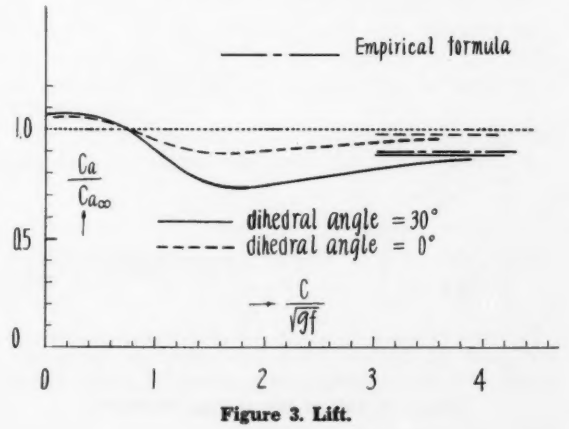


Figure 3. Lift.

gives 0.90 C_{a_∞}. From these we can see that by both methods the value is very comparable.

The resistance, which consists of the wave-making and induced resistance, is shown in Figure 4.

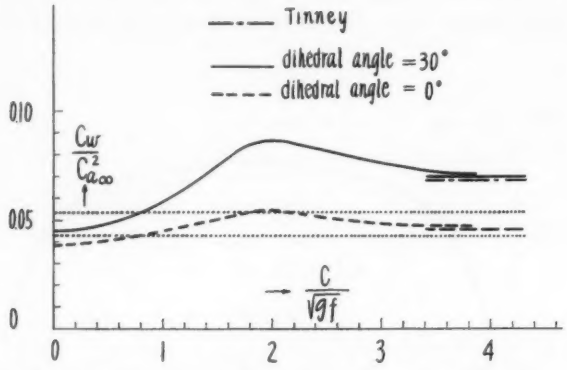


Figure 4. Resistance. (Dotted line shows the corresponding value in an infinite fluid.)

At the same time, the corresponding value in an infinite fluid can be calculated by Kondo's method [4] and is shown by the dotted line parallel to the abcissa; the wave-making and induced resistance increases by the effect of a dihedral angle and in particular the former is rather predominant. Further the resistance at extremely high speeds approaches the limiting value which is very proximate to Tinney's value.

In the meantime, from these considerations it can be concluded that a dihedral angle makes the effect of the free surface predominant and deteriorates the hydrodynamical characteristics of the submerged hydrofoil.

SPECIAL CASES

Now we consider the special cases from a practical viewpoint.

Vertical hydrofoil

Putting m=0 and l=1 in the aforementioned equations, we can obtain the corresponding expressions for the vertical hydrofoil. This problem has been examined only slightly by Maruo.[5]

The integral equation for determining the circulation, which is most fundamental, is given by

$$\Gamma(y)=-\frac{m_0}{8\pi}t(y)\int_{-\frac{b}{2}}^{\frac{b}{2}}\Gamma(\eta)\underline{\overline{K}}_v(y,\ f-|\eta|)d\eta+\Gamma_\infty\ (y) \qquad (20)$$

where

$$\underline{\overline{K}}_v=\frac{y^2-4(f-|\eta|)^2}{\{y^2+4(f-|\eta|)^2\}^2}+K_0{}^2e^{-K_0(f-|\eta|)}\left[\frac{4(f-|\eta|)^2}{K_0\{y^2+4(f\ -|\eta|)^2\}^{3/2}}\underline{\overline{K}}_1\right.$$

$$\left.-\frac{y^2}{4\{y^2+4(f-|\eta|)^2\}}(\underline{\overline{K}}_0+\underline{\overline{K}}_1)\right] \qquad (21)$$

As a numerical example, the lift and resistance are shown for aspect ratios 4 and 6 in Figures 5 and 6; the change of the characteristics due to the effect of free surface is comparatively small. This may be explained by the less prominence of the wave disturbance. Further, in order to examine this more minutely, the distribution of the effective circula-

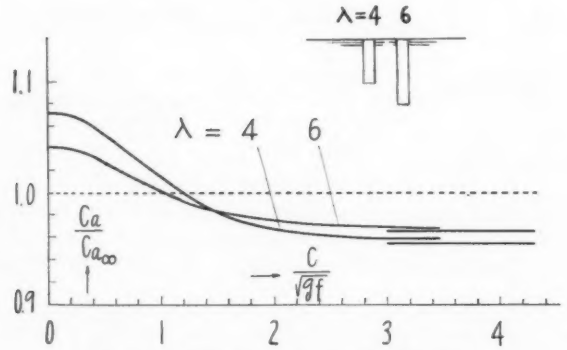


Figure 5. Lift of the vertical hydrofoil.

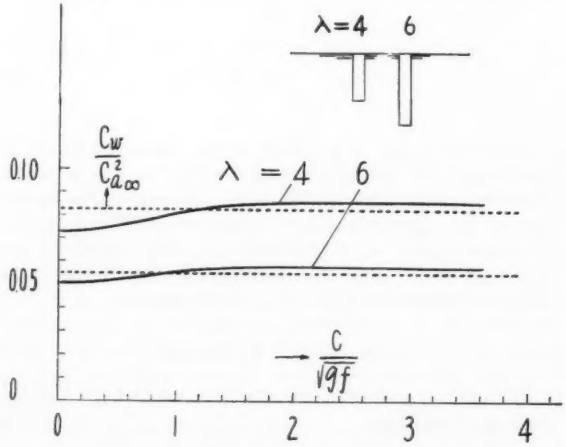


Figure 6. Resistance of the vertical hydrofoil.

tion is shown for an aspect ratio 4 in Figure 7; the effect of the free surface can be found locally only at the tip, where the circulation is very small, but on the whole its amount is comparatively small.

Horizontal hydrofoil

Putting m=1 and l=0 in the aforementioned equations, we can obtain the corresponding expressions for the horizontal hydrofoil which was discussed in detail in reference 6.

WAVE PATTERNS

The kinematical condition at the free surface is given by

$$\frac{\partial \phi}{\partial z} = C \frac{\partial \eta}{\partial x} \qquad \text{at } z=0 \quad \ldots\ldots\ldots\ldots\ldots (22)$$

Now, before entering into the wave patterns caused by the submerged hydrofoil of dihedral angle, we examine the wave patterns of the submerged hydrofoil of horizontal span.

For the sake of simplicity, we assume that the distribution of the circulation is uniform over the span. Substituting the velocity potential of the submerged hydrofoil of horizontal span [6] into (22), the surface elevation can be obtained. But we confine our interest to the regular waves in the rear which contribute to the wave-making resistance.

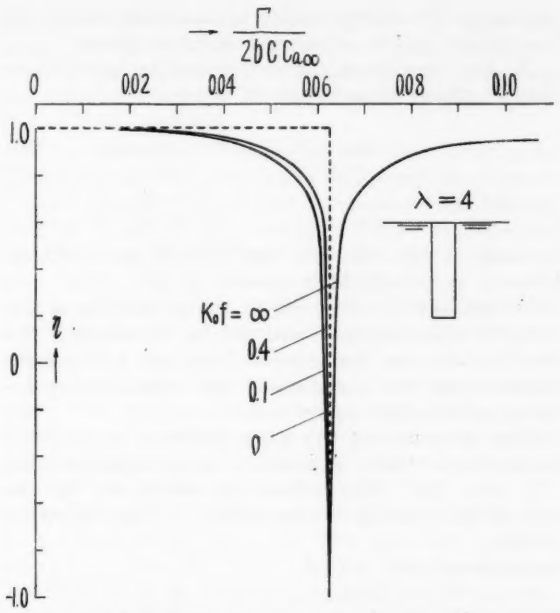


Figure 7. Distribution of the effective circulation over the span of the vertical hydrofoil.

$$\eta/\Gamma_0/\pi C = \int_{-\frac{\pi}{2}+\tan^{-1}\frac{y-b/2}{x}}^{\frac{\pi}{2}} \sec^2\theta \operatorname{cosec}\theta \; e^{-K_0 f \sec^2\theta} \cos\left[K_0 \sec^2\theta \left\{x\cos\theta + (y-\frac{b}{2})\sin\theta\right\}\right] d\theta$$

$$- \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}+\tan^{-1}\frac{y+b/2}{x}} \sec^2\theta \operatorname{cosec}\theta \; e^{-K_0 f \sec^2\theta} \cos\left[K_0 \sec^2\theta \left\{x\cos\theta + (y+\frac{b}{2})\sin\theta\right\}\right] d\theta$$

$$+ \left\{ \int_{-\frac{\pi}{2}}^{-\frac{\pi}{2}+\tan^{-1}\frac{y-b/2}{x}} - \int_{\frac{\pi}{2}+\tan^{-1}\frac{y+b/2}{x}}^{\frac{\pi}{2}} \right\} \sec^2\theta \operatorname{cosec}\theta \; e^{-K_0 f \sec^2\theta} \cos\left(K_0 \sec^2\theta \, x\right) d\theta$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

From the 1st and 2nd term in (23) we can see that the Kelvin wave generates at a point just over the tip, and becomes a free wave only somewhat aft. As the speed of the submerged hydrofoil is generally high, the diverging wave is rather predominant. On the other hand, from the fact that the 3rd term in (23) does not include the variable y, we can see that the 3rd term has the properties approximate to the two dimensional wave which propagates in the direction of advance. However from the range of integration the amplitude is larger at the tip than in the middle point of the span. Moreover from the relation

$$\lim_{x \to -\infty} (\text{the 3rd term}) = \lim_{y \to \pm\infty} (\text{the 3rd term}) \ldots . (24)$$

the amplitude diminishes at considerable distances aft and to the side. Therefore it may be said that this wave exists only in the vicinity of the submerged hydrofoil and is peculiar to the hydrofoil of finite span.

The surface elevation at extremely high speeds immediately behind the hydrofoil is given by:

$$\lim_{\substack{K_0 f \to 0 \\ x=0}} \eta/\Gamma_0/C\pi = x\left\{ \frac{\frac{b}{2}+y}{f^2+\left(\frac{b}{2}+y\right)^2} + \frac{\frac{b}{2}-y}{f^2+\left(\frac{b}{2}-y\right)^2} \right\} \quad (25)$$

(25) also expresses the fluid motion by the free vortex itself. Therefore this shows that the wave

motion in the vicinity of the hydrofoil approximates the vortex motion at extremely high speeds.

On the other hand, the corresponding two dimensional surface wave [7] is given by:

$$\lim_{\substack{K_0 \to 0 \\ x=0}} \eta'/\Gamma_0/C\pi = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

In other words, the two dimensional wave diminishes at extremely high speeds.

(25) and (26) correspond to the properties of the velocity potential and will aid in considering the relation between the wave-making and induced resistance and the variation of the wave-making resistance with the aspect ratio.

Now we examine the wave patterns by the submerged hydrofoil of dihedral angle. Substituting (3) into (22), the surface elevation can be obtained; the regular waves consist of the following terms:

undulatory term

$$\left.\begin{matrix} \sin \\ \cos \end{matrix}\left[K_0 \sec^2\theta \left\{ x\cos\theta + \left(y + \frac{b}{2} l \right) \sin\theta \right\} \right]\right\} \quad \ldots (27)$$

$$\left.\begin{matrix} \sin \\ \cos \end{matrix}\left[K_0 \sec^2\theta \left\{ x\cos\theta + \left(y - \frac{b}{2} l \right) \sin\theta \right\} \right]\right\}$$

$$\left.\begin{matrix} \sin \\ \cos \end{matrix}\left[K_0 \sec^2\theta \, x\cos\theta \right]\right.$$

range of integration

$$\left.\begin{matrix} \tan^{-1}\dfrac{y + \dfrac{b}{2} l}{x} \\ \tan^{-1}\dfrac{y - \dfrac{b}{2} l}{x} \end{matrix}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

$$\tan^{-1}\frac{y}{x}$$

Thus these show that the Kelvin wave generates not only at the point just over the tip, but also at the vertex of the dihedral angle, and the wave peculiar to the submerged hydrofoil of finite span has a large amplitude not only at the tip but also at the vertex of the dihedral angle. From this it may be understood why the wave-making resistance becomes larger in the hydrofoil of dihedral angle than one of horizontal span.

CONCLUSION

In this paper the hydrodynamical characteristics for the submerged hydrofoil of dihedral angle, which is surface-pierced at the tip, are considered in detail.

First, satisfying the boundary condition on the free surface, the velocity potential is introduced and then the fluid motion and the induced velocity are examined. From the assumption of the lifting-line theory, an integral equation is introduced for determining the circulation over the span and then the numerical method is presented for solving this integral equation.

Numerical calculations are carried out and compared with the up-to-date results. Lastly the regular waves caused by the submerged hydrofoil of dihedral angle are considered.

The author wishes to express his gratitude to Prof. F. Numachi and Prof. S. Fuchizawa for their many cordial guidances.

REFERENCES

1. E. R. Tinney, "Experimental and Analytical Studies of Dihedral Hydrofoil," St. Anthony Falls Hydr. Lab., Univ. of Minnesota, Proj. Rep. No. 41, 1954.
2. P. Kaplan, "The Drag of Dihedral Hydrofoils below a Free Surface," Note No. 381, E.T.T. Stevens Inst. of Tech., 1956.
3. Bülles, "Das Tragflügelboat," Jahrb. Schiffb. Gesells. Bd. 46, 1952.
4. K. Kondo, "Induced Drag of a Monoplane Wing of Dihedral Angle," Rep. of Faculty of Engineering, Univ. of Kyushu, vol. 15, 1940.
5. H. Maruo, "Effect of the Water Surface on the Wing." *Jour. of Soc. of Nav. Arch. in Japan*, vol. 86, 1953.
6. T. Nishiyama, "Lifting-Line Theory of the Submerged Hydrofoil of Finite Span," Part I, JOURNAL OF AMERICAN SOC. OF NAV. ENG., August, 1959.
7. T. Nishiyama, "Hydrodynamical Investigation of the Submerged Hydrofoil," JOURNAL OF AMER. SOC. OF NAV. ENG., August, 1958.

DISCUSSION

By Dr. B. L. Silverstein, Ship Design Division
Bureau of Ships

In this paper, Professor Nishiyama has made a significant contribution to the theory of hydrofoils. Reference (1), Tinney's St. Anthony Falls report of November 1954, is, at present, the most useful report on dihedral hydrofoils. It is recommended that the reader scan this report for background information. Tinney, however, used a semi-empirical approach, which though valuable, does not delve deeply into the fundamental problem of determination of the circulation distribution. Professor Nishiyama has very ably filled this void.

The use of the lifting-line theory (replacing the

hydrofoil by a bound vortex) should be a very good approximation. Most of the envisioned practical hydrofoil boats using surface-piercing dihedral foils will have a high aspect ratio and a low loading. There is no doubt that a lifting-surface theory would yield little of significance over the lifting-line theory.

Professor Nishiyama utilizes the same methods and procedures that he developed in earlier papers on hydrofoils for this JOURNAL. This is summarized succintly in his conclusions.

It is interesting to note that the dihedral hydrofoil is a very general foil. When the dihedral angle, β, is zero, we have the flat submerged foil; with $\beta=90°$, we have the vertical strut at angles of attack. Both cases are discussed in this paper. Considerable work has been done, of course, by Wu, Nishiyama and others on the flat foil, but very little exists for the vertical foil. This latter case is importportant. One or two vertical struts are used to support the flat foils on some hydrofoil boats. It is important to determine the side forces exerted by these struts in a turn. In many cases, the rudder is a moveable portion of one of the vertical struts. The lift and wave-making resistance are of interest, but perhaps more important are spray resistance, cavitation and ventilation. These problems will all be considered in experimental programs presently underway at the David Taylor Model Basin and elsewhere.

It is interesting to note the comparison between Tinney's and Nishiyama's results, shown on Figures 3 and 4. Tinney treated just the case of high Froude number (high C and small f). There is excellent agreement at Froude numbers above 4. Nishiyama has shown though, that this formulation can be considerably in error at Froude numbers of about 2, which may be of importance in the take-off condition.

On the basis of the results of this paper, it appears that the smallest dihedral angle is the most desirable. However, as Tinney points out, a large dihedral angle is very useful in order to avoid separated flow at low angles of attack.

This paper by Professor Nishiyama should provide excellent quidance for the extensive experimental program that is underway on the dihedral hydrofoil. It is an excellent example of the concentrated effort being made in Japan on the theoretical problems of wave resistance.

A theory that the universe is hot, instead of cold, has been proposed by scientists from Harvard University and Cambridge University. The hot universe theory contains an explanation for puzzles such as the origin of cosmic rays, galaxies, and a galactic radio glow which has been observed. This theory holds that space is filled with hydrogen atoms having a velocity equivalent to a temperature of about one hundred million degrees, but in a concentration of one or two per cubic yard of space. Compared with these energetic atoms, the star galaxies themselves are cold. As such galaxies speed through space, leaving a cold pocket in their wake, the hot intergalactic hydrogen condenses. This process is supposed as possible for the birth of new galaxies. Professors Thomas Gold and Fred Hoyle, originators of the theory, believe that hot hydrogen clouds surrounding galaxies have sufficient energy to emit radio waves which have been observed.

—from SCIENCE NEWSLETTER
July 11, 1959

A new supersonic guided missile, TARTAR, is now in production for installation in Navy ships. The completed missile is fifteen feet long and slightly more than one foot in diameter. Miniaturization techniques have been used to package the guidance, propulsion and destruction systems into a small, light weight air frame. The missile contains a dual-thrust rocket motor consisting of a high-thrust, short-duration burning period which serves to launch and accelerate the missile to supersonic speed, after which a lower-thrust, longer-duration burning period maintains the speed. The missile is scheduled to be installed in guided missile destroyers now under construction and in three guided missile cruisers now under conversion.

—Defense Department News Release

Explorer VI, launched in August, is the most complex satellite yet placed in orbit by the United States. It completes one revolution every 12.5 hours. Having an apogee of 25,000 miles and a perigee of 150 miles, the satellite will cover a larger volume of space near the earth than any previous vehicle. It is expected to have a lifetime of about one year. It has at its center a five-pound rocket which can be fired on signal to lengthen its life. The 142-pound package contains three radio transmitters, two receivers, three devices for mapping radiation belts, a device for measuring orbital velocity, two magnetometers for magnetic field data, a photo-cell for light intensity measurements, a detector for micrometeorites, radio-wave instruments, and the necessary batteries to power these instruments including 8,000 solar cells for recharging the batteries.

—from SCIENCE NEWSLETTER
August 15, 1959

Experiments have recently been conducted by the British in the use of hydrazine for chemical deoxygenation of feed water. Hydrazine is a compound of nitrogen and hydrogen having the formula N_2H_4. In the presence of oxygen and heat it forms free nitrogen and water, the reaction being complete at 350°F. Above this temperature hydrazine decomposes into ammonia and free nitrogen. Tests were conducted in a cross-channel steamer having a maximum feed system temperature of 210°F and having a history of difficulty with dissolved oxygen. The tests showed that oxygen was kept at a level of about 0.01 ml. per liter at the feed heater discharge; that ammonia was maintained at a constant level, keeping the pH at about 9.0, with no tendency to increase; and that no evidence of increased copper in the feed water from the presence of ammonia was evident. It was concluded that no serious difficulty should arise in the application of hydrazine to marine boiler treatment for effective deoxygenation.

—from THE MARINE ENGINEER AND NAVAL ARCHITECT
June, 1959

COMMANDER BERNARD M. KASSELL, USN

MARINE ENGINEERING NOTES FROM THE SOVIET PRESS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B. S. degree in Military Science from the latter institution. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He is currently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service Office, Morocco.

TANKER BUILDING

LATE IN JULY IT became apparent that the tanker building program, both within the Soviet Union, as well as in those countries engaged in meeting orders for the Soviet Union, had undergone certain changes worthy of note.

The *Kazbek*-class program appears to have run out, three deliveries in 1959 have included *Kom-Somolyets Ukrainyl, Tbilisi,* and *Yelnya* up to the time of this writing, to be replaced by two programs, both of which involve larger tankers.

One of these two programs is the *Pekin*-class program (See "Notes" in the May, 1959, JOURNAL) known to include at least three units. Besides *Pekin,* there are *Varshava,* under construction in the Baltic Shipyard, and *Budapesht.* The latter two are scheduled for service in 1960.

The second of the two programs is that involving a 17,000-ton capacity series, designed to carry four different grades of petroleum products between ports in the Soviet Union, as well as to other countries. This series is to be propelled by a gas turbine installation in the 13,000-hp range. Variable pitch propellers are to be installed and remote controls for the engines and propellers will be installed on the bridge. "Automatic" docking winches will also be fitted.

The shallow-draft tanker program (See "Notes" in the May, 1957, JOURNAL) has been underway within the Soviet Union for some years, but has terminated with *Samyed Vurgun,* 15th or 16th in the series. The Navashino Shipyard, builder of the class, now has orders to build other classes with the result that Bulgaria's Georgi Dimitrov Shipyard will take up where Navashino left off. The first Bulgarian-built tanker in the series has been named *Pamyati 26 Komissarov* and is now under construction. *Fedor Gubanov* is believed to be the second of the class building in Bulgaria.

The *Pevyek*-class program for Finland will continue and, in addition to this 4000-ton capacity class, another class, of 1500-tons is forecast.

The Stalingrad Shipbuilding Yard has already produced the first of the 3300-ton river tankers, tested during this past river season. The program

calls for 30 units in this class. Other tankers of 5000-tons and 2800-tons are talked about and a total of 20 of the latter has been mentioned. The former is a design of the Stalingrad Shipbuilding Yard and is to have a speed of 11 knots. It will be used for through runs from Astrakhan to Leningrad and the incorporation in the design of certain automatic features, as well as the installation of remote controls, will permit halving the personnel normally carried on a ship of this size. Yet other production plans for the river fleet call for 20 tankers of 150-tons capacity each to be built in the Lenin Shipyard in Astrakhan.

TANK CLEANING

In a discussion of this subject in the May, 1957, JOURNAL it was pointed out that the Soviet Union was indeed a laggard in developing means to cut down the time spent on this disagreeable job. On 30 April 1957, the Ministry for the Maritime Fleet had issued a directive to the Technical Administration, Central Planning-Design Bureau No. 3, and the Black Sea Steamship Company, to carry out certain experimental work in cleaning cargo tanks in tankers, as well as bunker fuel tanks in dry-cargo ships operating on liquid fuels, utilizing mechanical means wherever possible.

Some of the fruits of these experiments include a hydraulic washing machine which has received the designation "MM-3," and which is now said to be in serial production in certain of the enterprises subordinate to the Black Sea Steamship Company. It has been directed that the unit be installed on twenty *Kazbek*-class (approximately half of the total now operating) as well as on thirteen tankers operating with the Caspian Steamship Company. The installation work is to be completed this year. In addition, work is to be undertaken to mechanize the cleaning of tanker tonnage assigned to the Danube Steamship Company. The program requires that tank cleaning equipment be installed in all tankers by 1963.

However, it develops that no single type of washing machine has been found to be completely satisfactory for all needs so that more work is required in the development of the additives and washing powders now used with the machines. The Collegium of the Ministry has noted that the Caspian Roadstead Steamship Company, in the winter 1958-59, made good use of washing machines and the additive "ML-2" in combination with its new cleaning station, a floating steam and pumping station, which had been placed in service not long before the winter set in. Trials conducted in cleaning oil barges which had been loaded with mazut "M-80" were said to have yielded excellent results. The tanks needed no degassing and the bulkheads were clean enough to eliminate the need for hand cleaning. A 4600-ton capacity barge was cleaned in 36 hours and hand work in connection with cleaning was cut from 2900 man-hours to 90.

Contrasted with the performance of the Caspian Roadstead Steamship Company was the far from satisfactory use made of mechanical cleaning devices in the far more important Black Sea Steamship Company. None of the tests directed in 1958 were carried out, despite the fact that various machines, powders, etc., had been made available and, to varying degrees, had been furnished to all of the *Kazbek*-class tankers. As a result, the company still has no procedures for mechanical cleaning and no steps have yet been taken to comply with previous directives on the subject. This non-compliance has resulted in sharp criticism of the company's top officials, with most of the blame heaped on the shoulders of Chief Engineer Yermoshkin.

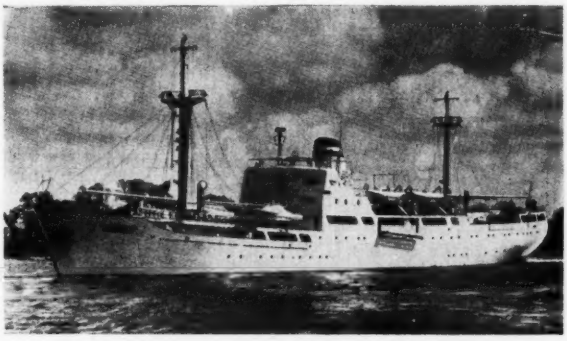
Administrative displeasure is based on figures provided by the Ministry's Technical Administration which show that use of the cleaning equipment would eliminate demurrage of 783,000-ton-days per year, a figure which represents loss of 95,900,000-ton-miles of performance. The total saving to the company could amount to some 1,568,000 rubles per year. Savings to be obtained by the use of mechanical means for cleaning tanker barges run to some 1.5 million rubles per year.

In sum, the Black Sea tankers, all of which appear to have been delivered without means for cleaning tanks, in five years have lost sufficient time in which to have performed 130 million ton-miles, a performance which, when equated to rubles, is the equivalent of a loss in revenue in excess of 2 million rubles.

RESEARCH SHIPS

In discussions on Arctic research which have appeared in previous issues of the JOURNAL, mention has been made of various research ships dispatched by the Soviet government as part of its contribution to the International Geophysical Year program. Many of these ships have been converted to such use (i.e., the icebreaking cargo carriers *Ob* and *Lena*, small woden ships such as the Finnish-built *Shtorm*, converted trawlers such as *Akademik Vavilov* and *Akademik Kovalevskiy*) but others have been specially designed or converted while in the process of construction. One such is the steamship *Mikhail Lomonosov*, known as the flagship of the Academy of Sciences of the USSR. Actually operating for the Maritime Hydrophysical Institute of the Academy, the ship may prove interesting to readers who are concerned with the development of similar types in the United States.

The Neptun Shipyard in Rostock, East Germany, was commissioned to build the ship which was completed in time to arrive in Leningrad in September, 1957. From Leningrad she proceeded to the Riga Shipyard for fitting out with the equipment and installations needed to carry out the mission assigned



Soviet research vessel MIKHAIL LOMONOSOV

for early in 1958, at which time she sailed for the first Atlantic expedition of the year. By July, 1958, she was one of nine research ships under the flag of the Soviet Union engaged in making observations for the IGY program. By May, 1959, after what appears to have been the third expedition for the ship in the Atlantic area, sufficient details had been published to indicate the type of ship found by the Soviet Union to satisfy the operational needs of wide-ranging ocean research. *Mikhail Lomonosov* is classed in the Register of the USSR as L*R4/1S and has the following basic characteristics:

Length overall, feet	336
Length between perpendiculars, feet	312
Beam, feet	46
Height of side, feet	26
Draft, full load, feet	19
Draft, empty, feet	13
Displacement (0.03 tons/cubic foot), tons	5960
Gross Registered Tons	3898
Net Registered Tons	1195
Crew	64
Expedition members	64
Speed, knots	13.6
Main engine, ihp	2450

The all-welded hull is built on the transverse system of framing with watertight bulkheads dividing the ship into eight subdivisions, any one of which may flood without effecting stability. The ship has two full decks, a forecastle and an extended quarterdeck with the house located at its forward end. The well between the forecastle and the house was designed to provide stowage for the deep water anchor and associated equipment.

Fuel capacity is sufficient for steaming 11,000 miles at an average speed of 13 knots, providing an operating period of 35 days. In addition, the ship can spend 30 days in normal drift conditions. Feed bottoms hold sufficient water for 21 days of full speed operations but a distilling plant with a capacity of 30 tons per day is also installed to provide makeup feed water and water for ship's needs as well.

The main engine is a model LES-10 steam piston engine fitted with an exhaust turbine of the Bauer-Vakht type. The turbine is connected to the shaft through a two-stage transmission with a hydraulic clutch. The main engine is rated at 1710-ihp, the exhaust turbine at 740-ihp. Two assymetrical water-tube boilers with a productivity of eight tons of steam per hour at a pressure of 220 psi provide main propulsion and auxiliary steam. The heating surface of the oil-fired boilers is 2260 square feet. Rotating burners are installed in the boilers and an "Ascania" system of combustion control is used to perform usual boiler servicing. The main engine is connected to a 4-bladed propeller made of a special brass casting which has a diameter of 190 inches and a pitch of 197 inches. The spare propeller is of cast steel.

Three direct current, 230 volt turbo-generators are installed in the engine room, two of which are rated at 270-kw, the other at 150-kw. A 90-hp diesel engine serves as the prime mover for a 57-kw emergency generator. In addition to other auxiliary machinery, the ship is equipped with a machine shop located on the platform in the engine room and a technical shop for use of expedition personnel is located in the bow.

The streamlined rudder has an area of 86 square feet and is operated by an electric steering motor rated at six kilowatts. An emergency hand operated drive is located in the wheel house. A capstan, mounted aft, has a further, emergency, tiller rope arrangement to the rudder in case of need. A 30-kw anchor windlass handles the 2-inch chain and Hull anchors. The two forward anchors weigh 5850 pounds each and each of the two chains is 900 feet long. An Admiralty-type stop anchor of 1800 pounds is installed, while a spare anchor weighing 4550 pounds is carried on deck. The anchor windlass can be hand operated in an emergency. Rounding out the deck equipment are three 3-ton booms, four 1.5-ton booms and one 10-tonner. Five electric winches handle the booms. Light, 220 pound capacity booms, are fitted two to the foremast and one to the main.

Special equipment includes a deep-water anchor, including the cable which is 50,000 feet long and which ranges in diameter from 1 to ½ inches, an Admiralty-type anchor weighing 1100 pounds, eight "Okean" boat winches, a deep water trawl with 25,000 feet of cable, fathometers, a helicopter platform, two motor cutters, and other equipment. Two 58-man life rafts made of an aluminum alloy and equipped with a hand-drive for propulsion purposes are part of the life-saving equipment, together with two wooden life boats, all of which are installed in davits which are fitted with hand-operated winches.

Crew and expedition members are housed in one and two place cabins furnished with ventilation and heaters so as to ensure heating of air to 65°F when the vessel is operating in northern latitudes.

Radar, RDF, and other navigational equipment are standard and are in addition to special gear carried for expedition uses on deck and in the 16 laboratories with which the vessel is fitted.

POLISH-BUILT CARGO CARRIERS

Poland's contribution to the Soviet merchant marine has included a class of cargo carriers of some 11,000-tons deadweight, the first of which, *Leninogorsk*, was turned over to the Soviet Union in November 1958, followed by *Solnechnogorsk* in January 1959. Characteristics of the class include:

Length overall, feet	506
Length between perpendiculars, feet	465
Beam, amidships, feet	64
Height of side to shelter-deck, feet	41
Height of side to main deck, feet	31
Draft, full load, feet	29
Draft, mean, empty, feet	15
Displacement, tons	16890
Weight empty, tons	5890
Useful cargo capacity, tons	9750

Watertight bulkheads divide the ship into eight compartments: forepeak, holds 1, 2 and 3, engine room, holds 4 and 5, and afterpeak. Grain capacity of the holds is 636,000 cubic feet, for general cargo the figure is 500,000 cubic feet. Mechanical hatch covers are installed and the largest boom capacity is 60-tons.

The class is built to the rules of the Register of the USSR, class L*R4/1S for ice classification as well. However, the main engine, the diesel-generators and individual pieces of auxiliary machinery were manufactured according to the rules of, and under the supervision of Lloyd's. Most of the auxiliaries, however, were manufactured according to the rules of the Register of the USSR under the supervision of the Polish Register (PRM).

The main engine is an 8-cylinder, vertical, two-cycle, solid injection, single acting engine, Fiat type C750, supercharged. The engine, with a bore of 29.5 inches and a stroke of 42 inches, will develop 8000-ehp at 125-rpm. Fuel consumption is 0.363 pounds/-ehp/hour and the capacity of bunkers is such as to provide a standard cruising radius of 10,000 miles. However, the supply of fuel in the tanks can be increased to 1000 tons to provide a range of 20,000 miles, if needed. Standard endurance is 40 days. The ship is rated as a 17-knot type.

Fiat diesel engines are used to drive the generators, the three type C256E engines, 10 inch bore and 16 inch stroke, driving 250-kw, direct current, 220-volt generators. Each engine is rated at 410-ehp at 470-rpm. A limited, emergency lighting system, fed from 24-volt battery, as well as a 12-volt lighting system, is installed.

Living quarters are provided for a 42-man crew and nine passengers.

Both of the ships mentioned were to be assigned to the India trade, but shortly after mid-year it was noted that *Solnechnogorsk* was in the Far East.

BULGARIAN CARGO SHIPS

In previous discussions of shipbuilding for the Soviet Union in countries other than the USSR, and particularly in those countries which have come to be part of the Soviet colonial empire, frequent mention has been made to the Register of the USSR and its rules. Usually this mention has been made in connection with those ships delivered directly to the Soviet Union. More recently, however, it has begun to appear that the influence, if not the complete authority, of the Register has been extended to the various captive countries.

There is at least one permanent representative of the Register of the USSR in Bulgaria, presumably in Varna, the site of the Georgi Dimitrov Shipyard, which is also building the shallow draft tankers mentioned earlier. This representative has reported that two shelter-deck general cargo carriers, *Varna* and *Burgas*, were built to Register class L*R4/1S and carry this class into the Bulgarian merchant marine. Characteristics of the two include:

Length overall, feet	302
Length between perpendiculars, feet	280
Beam, feet	44.5
Height of side to upper deck, feet	27
Draft, full load, feet	18.5
Cargo capacity, tons	2727
Main engines, hp	2x1000
Speed, full load, knots	13
Cruising radius, miles	7500
Crew	37
Passengers	12
Cargo capacity, three holds, cubic feet	170,000

Cargo handling equipment consists of 10 booms of 3 to 5 tons capacity and two heavy lift booms of 10 and 30 tons each.

Main propulsion is provided by two 4-cycle diesel engines SKL type R8DV, 148A, manufactured by the Karl Libknekht Works in East Germany. Each of the supercharged engines develops 1000-eph at 375-rpm. The engines are coupled to a single shaft through a hydraulic-gear reduction with a ratio of 3.75:1.

Ship's service lighting and power are furnished from two diesel-generators of 100-kw each for the 200-volt direct current network. An in-port unit of 35-kw completes the installation.

The 1935-GRT vessels are equipped with the "latest" of navigational equipment.

THE *"Andizhan"* CLASS

East Germany has contracted to build a class of cargo carriers, the first of which has been named *Andizhan*, which will total 81 units by 1965, all of them for the Soviet Union. This is by far the largest projected program for the Soviet merchant

The motorship ANDIZHAN, built in East Germany

marine and it is therefore suggested that this particular design and class was selected because it offers the very best all-around capability for future use. Six of the class were known to have been in service in mid-1959, five of them operating in the Far East. Other indications pointed to use of available units for Arctic operations as well. In fact, they are classed for ice use under the Register of the USSR rules and are certified for unlimited use within a range of 5000 miles at an average speed of 13.5-knots. Characteristics published for the class include the following:

Length overall, feet	343
Length between perpendiculars, feet	314
Beam, feet	47.5
Height of side, feet	26
Draft, feet	21.6
Deadweight, tons	4310
Maximum displacement, tons	6659
Cargo capacity, tons	3985
Cubic feet of space for general cargo	190,000
Cubic feet of space for grain cargo	200,000
Gross Registered Tons	3300
Net Registered Tons	1600

The ships are equipped with eight 5-ton cargo booms, four on the foremast and four on the mainmast, as well as with two heavy lift booms, one for 40 tons, the other for 15. MacGregor hatch covers are used for the four hatches.

Main propulsion consists of two four-cycle, reversible, supercharged diesel engines Type 8SVuA rated at 1250-ehp each at 333-rpm. They connect to the single shaft through a common, single-stage reduction gear and an hydraulic clutch. Maximum shaft revolutions are 105 per minute and guaranteed fuel consumption is 0.363 pounds/ehp/hour plus 5 per cent. The shaft is 117 feet long, in five sections and a tail shaft to which is fitted the four-bladed, cast bronze propeller which is 14.7 feet in diameter and which has a pitch of 14 feet.

Ship's service lighting and power is furnished by three alternating current generators rated at 230-kva, 400-volts. Diesel drive is provided for each generator by a four-cycle engine running at 500-rpm and rated at 250-hp. The engines are the product of the Karl Libknekht Works. The electrical network is 3-phase AC, 380-volts for power and for remote controls and lighting this is dropped to 220-volts. An emergency lighting circuit of 24-volts is installed, as well as a 12-volt repair circuit, the latter two presumed to be battery fed.

A vacuum-type distilling plant with a capacity of 3-tons per day is a new innovation. This is said to be the first such installation to be made in a Soviet-flag ship. Also noted on the equipment list is an "Atlantic" oil-water separator, "Simplex" steam pumps, automatic boiler fuel injectors of the "Monarch" type, and a "Lamont" type utility boiler.

Berthing is provided for 37 crew members, one berth for a pilot, and two sick bay bunks. The captain, chief engineer and chief mate have a suite made up of an office and a bedroom. The other officers are in single cabins, the crew in double cabins.

DREDGERS

Czechoslovakia has, since 1952, been a supplier of dredging equipment to the Soviet Union. The first model dredge produced in Czechoslovakia by the Cheshska Lodenitsa Shipyard in Prague was designated SB250 and was renamed the DE-type in the Soviet Union. By the end of 1958 38 of the dredgers had been delivered.

As a result of lessons learned in using the first dredger, there now is underway a program which calls for the construction of a unit bearing the designator SB725. The original dredger, as well as the new one, is a diesel-electric type, non self-propelled, with remote controls installed for operation of the dredging machinery. Differences in the two may be seen from the following:

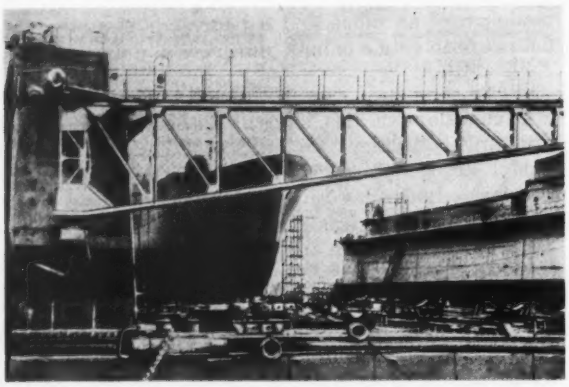
	SB250	SB725
Capacity, designed, cubic yards per hour	325	950
Length of spoil pipe, 1 yard lift, feet	1300	1800
Greatest depth of end of suction, feet	20-36	20-36
Relative power of cutter head, kwh/yd^3	0.083	0.096
Length of hull, overall, feet	174	181
Beam, feet, greatest	30.5	31.2
Height from base, feet	30	32
Draft, designed, feet	4.2	4.5
Displacement at designed draft	462.5	563.0
Crew spaces	35	35
Pump engine, ehp	380	800
Engine rpm	325	325
Electrical station, kw	180	260
Operating time, hours	300	320

Yet a third type of dredger, SSB350, will be built in Czechoslovakia to be shipped in disassembled form to destination for assembly. The sections will be of such size that rail transport can be used, the largest of the sections measuring 46x12.8x7.2 feet and weighing 34 tons. This model too will be equipped with a diesel installation and, whereas previous models were designated as suitable for use in lake-type conditions, this model, carrying a 17 man crew and designed to handle 460 cubic yards of spoil per hour, will be certified for river use only.

Other, smaller, units are also in production or planned for the near future.

REFRIGERATOR-TRAWLER

During the summer of 1958 the trawler *Mayakovskiy* was tested and accepted for service as the first of a series of refrigerator-trawlers. More complete details as to design and construction have now been published, revealing that the ship is a single screw type with a stern ramp through which the trawl is launched and recovered. The engine room is amidships. The most recent of the series, *Belinskiy*, has been fitted with a variable pitch propeller. The vessels are designed to catch and process the fish, down to and including the preparation of fish meal from the waste products. In addition, fast freezing of the catch as desired is possible. Classed in the Register of the USSR as L*R4/1S



Refrigerator-trawler in floating dock prior to "launching"

(Trawler-Factory), characteristics include:

Length overall, feet	278
Length between perpendiculars, feet	246
Beam, designed, feet	46
Height of side to upper deck, amidships, feet	33
Mean draft at departure (includes all stores and packing materials, but no cargo), feet	18
Mean draft on return (100% fish products, 25% stores), feet	18
Displacement, departure, tons	3658
Displacement, return, tons	3638
Deadweight, departure, tons	1301
Hold capacity, cubic feet:	
No. 1 Refrigerated	10,000
No. 2 Refrigerated	22,000
No. 3 Refrigerated	14,500
Fish Meal	6,000
Canned Products	4,400
Capacity of fish oil tank, cubic feet	1300
Propulsion installation, ehp	2000
Speed at 3658 tons displacement, knots	13
Crew	104

Endurance is given as 80 days, of which 60 may be spent in working. Fuel capacity is such as to provide a cruising radius at full speed (assuming no industrial operations) of between 16,000 and 17,000 miles.

The main propulsion engine is a product of the "Russkiy Dizel" Works, Mark 8DR-43/61V1, certain details concerning which include:

Rated horsepower, ehp	2000
Rated rpm	250
Bore, in.	15
Stroke, in.	24
Number of cylinders	8
Fuel consumption at 2000-eph, lb./ehp/hr, max	0.385
Engine life, hours	20000
Weight of engine, dry, tons	65

The engine is described as of the vertical type, reversible, two-cycle, single-acting, trunk-type with jet spray fuel injection.

The ship's service network is fed from four diesel-generators and is a three-phase, alternating current system of 230-volts. Each generator is rated at 224-kw and is driven by a Mark 6 Ch-23/30 engine with basic characteristics:

Rated horsepower, ehp	300
Rated rpm	750
Bore, in.	9
Stroke, in.	12
Number of cylinders	6

In addition to the main units, a 63-kw auxiliary for use at anchor or in port and a 25-kw unit for emergency use, are available.

Two water-tube boilers, Mark KVS-30/1, each of which can generate two tons of steam per hour at 70 psi, provide steam needs for factory purposes, as well as for the distilling plant and for ship's heating needs. The distilling plant, Mark IYeR-7, produces 7 tons of fresh water per day.

During trials in the Black Sea *Mayakovskiy* logged 13.7-knots and was able to go from full ahead to full astern in 3 minutes 5 seconds, during which time the vessel travelled 6.2 times her own length. During trawling operations best turns were within the range 115-125-rpm for a speed of from 3 to 3.5-knots.

The reversible pitch propeller fitted to *Belinskiy* is designated VRSh VR-394 and is an hydraulically operated, 14-ton unit. The blades move through an arc of 38° and main control stations in the fore and after houses are equipped with propeller pitch indicators. The main propeller drive is electrohydraulic, with a hand pump installed for emergency use. Propeller diameter is 9 feet, and is three-bladed. *Belinskiy*, during trials, went from full ahead to full astern in 2 minutes 15 seconds and travelled but 4.2 ship lengths.

Construction of the trawlers takes place in twelve "technological" stages. This is to say that building is done by means of the block-sectional method wherein the hull and superstructure are divided into blocks which are prefabricated in a group of shipbuilding shops in the I. I. Nosenko Shipyard in Nikolayev on the Black Sea. Assembly of the ship from the blocks and sections takes place in four positions, or steps, as the six main blocks in the hull and the three main blocks of the superstructure are built up to the finished trawler.

The first five of the twelve construction stages are concerned with the cutting and shaping of the steel, the assembly and welding of individual sections and units of each of the nine main blocks and the installation of machinery and equipment in certain areas. The first stage which actually takes place on the ways is the 6th, at which time blocks 1, 2, and 3 are assembled, the main engine is set in the engine room and other assembly and installation work is done. The second way position accomodates the 7th stage of the building cycle and it is during this stage that the engine, shafting and propeller are installed, as well as other main and auxiliary machinery. Stage number 8 occurs at the third way position where necessary shipfitting and hull work is done in compartments, certain of the painting is accomplished, the main switchboard is installed and deck machinery is put in place. The 9th stage occurs at the fourth way position, during which the stack is set in place, masts are stepped, life boats and davits

installed, more painting done and, in fact, all work needed prior to launching is completed.

During all this time the vessel has been mounted in a cradle on wheels, in turn set on rails. At the termination of work required during the 9th stage the carriage is moved into a floating dock, which is then flooded and the hull is floated out and tied up to a finishing dock. At this dock the 10th stage work is done. During this stage the ship is prepared for dock trials, which then take place during the 11th stage. The 12th, and final stage is that during which underway trials occur, post trial repairs are made, and the ship delivered.

SEAGOING TIMBER CARRIER

Visitors to the Moscow Fair during the summer were shown models of a seagoing timber carrier which could, it was claimed, double as a grain carrier. Register class is UL*R4/1S and the first of the unspecified number of units is to be laid down this year. The four hatch vessel will be able to carry a total of 400,000 cubic feet of timber, 130,000 cubic feet of which will be deck loaded. Deadweight of the timber is estimated at 5050 metric tons, while the grain cargo will load out at 5125 tons.

Main propulsion will be provided by a single-shell gas turbine, a reduction gear, four free-piston gas generators and associated auxiliaries. The turbine will have six ahead stages and two astern stages. Ahead power is given as 4000-hp at 5500-rpm for the turbine. Shaft revolutions will be 115 per minute at full speed. The astern stages develop a maximum of 1400-hp. A 3-stage reduction gear provides a ratio of 43.5 to 1. Each of the gas generators is a horizontal, 2-cycle engine with a freely moving piston directly connected to the compressor piston. Power developed in each is 1250-hp. The working gas produced by the generators, when the engine is operating for 4000-hp, will be at a pressure of 44 psi at 450°C. Each producer will provide 8.7 lbs. of gas per second.

Ship characteristics include:

Length overall, feet	400
Length between perpendiculars, feet	338
Beam, greatest, feet	53
Height of side, amidships, feet	27
Draft, feet	
with cargo timber	23
with cargo grain	22
Displacement, tons	
with cargo timber	9420
with cargo grain	8900
Deadweight, tons	
with cargo timber	5670
with cargo grain	5740
Gross Registered Tons	4750
Net Registered Tons	2260
Speed, knots	14

SARDINE BASE SHIP

One of the directives published at the XXIst Congress of the Communist Party called for Soviet fishermen to extend their areas of operation in the Atlantic and Pacific oceans. Compliance with the directive requires the acquisition, either by building within, or ordering from without, the Soviet Union new base, or factory ships to accompany the wide ranging trawler fleets and process the catch on the spot. The need for factory-type ships is a continuing one, despite the additions made to the fishing fleet in the past five and more years as a result of purchases or orders for new construction placed in shipyards throughout the world.

The latest of these factory types to be announced, a sardine base, was said to have been under construction in mid-1959 to Register class UL*R4/1. Designed to the following characteristics, the ship will displace 15,300 tons:

Length between perpendiculars, feet	478
Beam, greatest, feet	66
Height of side, feet	41
Speed, knots	14.5
Main diesel, ehp	6250

Artist's conception of the planned sardine base ship

Operational needs dictate a design which incorporates a long stern superstructure and a wheel house well forward. The hull is all-welded, with the exception of the connection between the sheer strake and the upper deck stringers amidships. In this area riveted construction will be used in order to form a "barrier" to prevent the spread of cracking should such develop in the welded hull during operations. Another innovation reported in the hull design is a longitudinal corridor in the vicinity of the double bottoms which is formed by two stringers running parallel to the centerline of the ship and serving as a vertical keel.

A helicopter platform will be installed and four medium trawlers (SRT) will be able to come alongside simultaneously in the open sea in 4-5 ball swells. Damage will be avoided by the use of air-filled, rubber and fabric fenders. Cargo handling gear will consist of four 2-3 ton rotating cranes, plus boom type lifts of up to 5-tons.

Four automatic processing lines, one for each trawler being handled, will be installed in the two amidships tween-decks and will handle all packing or other processing.

It is not known at this time whether this ship is a type different from that now under construction in quantity in the Gdansk, Poland, area, or is, in

fact the same ship. The Polish ship, five of which are identified as for the Soviet Union thus far, is of 11,540 gross registered tons and has, from Soviet sources, been designated as in the "10,000-ton displacement class."

SEA-RIVER CARGO CARRIER

The completion of the various hydro-electric installations on the Volga, Kama, and Don rivers has resulted in making possible direct shipments from river ports to sea ports on the Caspian and Black seas, as well as the other way around, without need to trans-ship. Soviet planners have talked for many years of the advantages to be gained from such shipments and, in fact, took the first step towards the accomplishment of the plan by the building of the *Oleg Koshevoy*-class of tankers. It has only been recently, however, that direct movement of oil has taken place, suggesting that certain operational difficulties had been encountered and, apparently, overcome.

In furtherance of the planning, there now has appeared the first of a series of ten dry-cargo ships for this mixed sea-river use. The construction of the first ship of the series, designed to carry cotton and timber in the Volga-Caspian basin, was begun in the Navashino Shipyard on the Oka River in 1958 and is reported to have the following characteristics:

Length overall, feet	394
Length between perpendiculars, feet	368
Beam, feet	49.5
Height of side, feet	21
Draft, loaded, feet	
River	11
Sea	13
Net cargo capacity, tons	
River	2500
Sea	3600
Displacement, loaded, tons	
River	4210
Sea	5310
Displacement, empty, tons	1598
Draft, empty, mean, feet	4.6
Displacement, in ballast, tons	3590
Draft, in ballast, mean, feet	9.2
Horsepower	1600
Speed, at draft of 10 feet, knots	11.8
Crew	27
Endurance, days	8

Construction is according to class L*R4/1S of the Register of the USSR, with additional stiffening being built in to enable the class to operate in the ice.

Main propulsion will consist of two diesel engines Mark 8DR-30/50-M55, indicating that modifications have been made to the original model. Each engine is rated at 800-ehp at 300-rpm and closed, fresh water cooling systems are now part of the design. The engines will connect to the shafts through a gear-clutch arrangement and will turn four-bladed cast brass propellers 6.4 feet in diameter fitted in nozzles resembling the Kort nozzle. Controls will be located in the engine room only, a fact which has caused criticism to be heaped on the designers for failure to comply with the directive of the XXIst Congress of the Communist Party concerning the introduction of automation on a large scale.

Central Planning-Design Bureau No. 4, in Leningrad, as part of its assignment to standardize shipboard equipment and parts, was to have developed a system of automatic and remote controls for the class and Central Planning-Design Bureau No. 6, in Baku, could have supervised the installation of the systems. However, it appears that the necessary cooperation between the two Bureaus was lacking, with the result that the first eight ships of the class will have neither automation nor remote controls.

Following a decision in May 1957 by the Soviet Government to establish a Siberian branch of the USSR Academy of Sciences, the construction of a "science town" has been started. Located 15 miles from Novosibirsk, the largest industrial and cultural center in Siberia, the new town is scheduled to cover about 3500 acres. It is expected to consist of 14 research institutes, a university, and the housing and other supporting buildings required.

—from INDUSTRIAL LABORATORIES
August, 1959

LIEUTENANT HAROLD L. YOUNG, U.S.N.

TECHNIQUES AND PRACTICES IN RECENT NAVAL STEAM TURBINE CONSTRUCTION

THE AUTHOR

graduated from the Massachusetts Maritime Academy in 1950 and from the U.S. Naval Academy in 1954. He then spent 3 years on the destroyer TWINING (DD540), 2 years of which were as engineering officer. He commenced post-graduate training at the Massachusetts Institute of Technology in June 1957 (Course: Naval Construction and Engineering) and will graduate in June 1960.

INTRODUCTION

WHENEVER one ventures beyond established fields or conditions, it is anticipated that unexpected troubles will be encountered and that new techniques must come forth to correct them. This has been true in the field of naval steam turbines. Changes in design have evolved—changes arising out of a desire for higher efficiency and shaft horsepower in the cruising range as well as the result of experience with prewar designs. The use of higher pressures and temperatures has opened up a whole new galaxy of problems and techniques. This was presented in no uncertain fashion with the trials of the experimental destroyer *Timmerman*: 2000 psi and 1050° F on one shaft and 875 psi and 1050° F on the other shaft—the highest steam pressure and temperature ever used for ship propulsion. In the following sections this author will present some of the more noteworthy features of current turbine design along with the problems from which they grew.

GENERAL TURBINE ARRANGEMENTS

Postwar emphasis on simplicity of operation and maintenance—in the face of much higher steam temperatures and pressures—renewed interest in the so-called "series-parallel" turbine used around 1920. In this unit two groups of stages are combined, through which the steam passes either in a series or parallel manner. When the high speed combination is in use, the steam is divided upon entering the turbine, part going through one group and part through the other. At cruising speeds, where the lower RPM requires a larger number of stages, steam passes first through one group and then through the other in a series arrangement. Our current *Forrest Sherman* class (DD931) typifies this construction. In both these speed ranges, however, steam enters at the middle, reducing the problem of sealing against casing leaks in the way of the shaft—a problem that prevails when separate high pressure and cruising turbines are used. Moreover, the transition from the cruising to high speed combination is simple—just the elimination of the cross-over valve on the DD445 class illustrates this. In addition, there is no danger of overheating the cruising elements due to windage friction since all blading is working.

It might appear then that we have come "full-cycle"—back where we were thirty-five years ago! *Basically* the turbine is the same but comparisons

do end there. The first use of the HP-IP combination evolved out of a desire to incorporate cruising elements in the steam turbine propulsion plant and thereby increase the unit's efficiency. The eventual change to separate cruising and high pressure turbines insured still higher efficiencies. The use of 615 psi-850° F steam, as on the DD445 and DD692 class destroyers, presented little difficulty. Now, however, with the higher pressures and temperatures we find ourselves back utilizing the earlier arrangement. Separate cruising and HP turbines *would* have been more efficient, since, by designing for the maximum steam conditions that would prevail in the unit, closer clearances would have been possible. But the problems would have multiplied in such a design. The windage friction generated in an idling cruising turbine would have been just one of the problems. At the higher rotating speeds of today the friction would be dangerously high, regardless of the effect of cooling steam.

It can be seen, then, that the HP-IP arrangement came forth as a compromise—a means by which the higher pressures and temperatures might be utilized in a relatively simple design, incorporating both simplicity of operation and ease of maintenance. In the instances where cruising turbines have still been used, the top of the cruising range has been extended from approximately 10 per cent to about 30 per cent of the designed SHP. Cruising turbine speeds have increased from the 10,000 RPM range to ranges from 12,000 to 18,000 RPM in postwar designs. The experimental *Timmerman* raises it in one instance to 24,000 RPM. But it is again emphasized that stringent design complications can set in where separate HP and cruising casings are used. Not only is difficulty experienced in keeping casing joints tight (since both rather small units must be designed for full pressure at their high pressure ends), but windage friction in the idling cruising turbine at full power can become a severe consequence. Consider also the cost aspect: one long rotor forging and one casing replacing two casings, two short rotor forgings, and a cruising reduction gear.

The low pressure turbine has undergone far fewer changes than the high pressure turbine. The temperature rise of the ahead elements continues to be the limiting factor on sustained astern operation; but postwar designs do allow for continuous operation astern at a slightly higher rating. This is made possible by increasing the axial blade clearance in these ahead elements (on the order of 1.5 to 2 times as much as compared to prewar figures). Some success has been met with the introduction of thin stainless steel sealing strips in the casings in an effort to counterbalance this increased axial clearance. The exit velocity loss has been reduced by designing for 25 inches of vacuum at full power vice the 27.5 inches formerly desired. This has resulted also in a substantial reduction in the annulus area of the last stage, a fact borne out by the following data:

	Designed vacuum at full power	Wheel Diameter	Blade length	SHP
DD 445	27.5"	38"	10"	30,000
Ex-DD 927 (DL's)	25.0"	34"	9"	40,000

The total number of stages has not been changed appreciably, nor has their distribution been altered to any great extent. Prewar staging distribution (cruising-HP-LP) was usually around 8-12-6. This can now be found to be 8-9-9 or 8-9-7. Since the heat drop has been increased by increasing the steam temperature 100-200°F and by doubling the steam pressure, with stages roughly the same, the end result has been that the turbine RPM must be increased. This is an increase from 5500-6000 RPM to 7000-8000 RPM for the high pressure unit, and a rise in the low pressure turbine speed from 4800 RPM to between 6000-7500 RPM. These figures emphasize the windage friction problem. While this article is directed towards the turbine unit itself, the reader cannot help but ponder a directly related problem of greater magnitude: with higher rotative speeds and power being generated, how might they be resolved into an effective reduction gear design where smaller and more quiet-running gears are continually being sought?

All these changes—denser steam, lower full power vacuum, higher turbine speeds, improved steam rates, and a more compact design—have meant a reduction in size and weight. Specific weight has been reduced 25-45 per cent. The high reduction in specific weight that is realized is probably the most noteworthy feature as far as combatant ships are concerned. Machinery weight represents a substantial percentage of ship displacement for naval vessels, a fact best illustrated by these figures:

	Lbs/SHP	Mach. WT./ Ship Displ.	SHP
Cruiser	31.4	10.7%	120,000
Destroyer	27.0	20.1%	80,000
28,000 T Tanker	155	2.6%	13.750
C4 Cargo	130	6.8%	22,000

Efficiency-wise the changes have not been as substantial. Increased steam pressure, by itself, reduces the maximum internal efficiency of the turbine on the order of 1 per cent for an increase of plant pressure from 600 psi to 1200 psi. Moreover, the increased pressure reduces the volume flow, causing a further adverse effect on the turbine efficiency. The increase in over-all turbine efficiency can only be explained in terms of improved designs, and, to a small extent, by the increase in superheat temperature.

MATERIALS

The materials used in turbine construction vary radically with the temperature for which the unit is designed. Up to 800° F plain carbon steels have

been employed successfully for forged rotors, cast cylinders and steam chests. At 850° F carbon steel with 0.5 per cent molybdenum can be assumed as standard for these components. Although this material has proven satisfactory for rotors and casings with temperatures up to 925° F, it has been found that the heat-affected zones adjacent to welds are apt to develop graphitization during prolonged operating periods, particularly in fine-grained aluminum-killed steels; and it is for this reason that the addition of chromium is made to the carbon-molybdenum steel. As operating temperatures approach 1000° F the resistance to creep falls off rapidly, necessitating the use of the group of ferritic steels containing molybdenum and vanadium, each of which possesses mechanical properties dependent on the heat treatment it has received. Figure 1 indicates the carbon content of the steels being discussed.

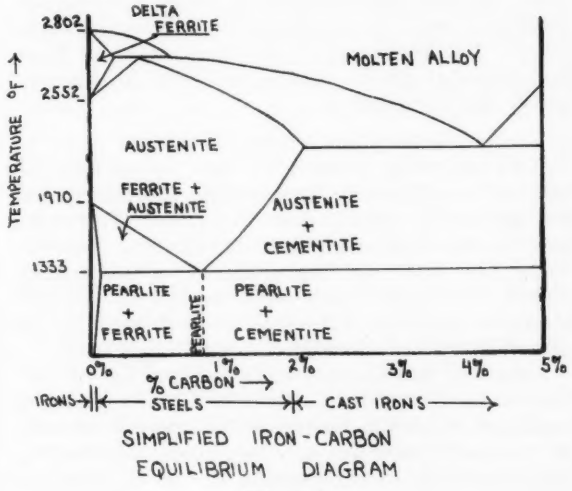


Figure 1.

The effect of creep in design considerations is an interesting and complex facet in itself. The necessity for close tolerances in turbines is obvious from an efficiency viewpoint, but the control of these clearances under the influence of creep is a difficult one. Creep—the deformation of the metal with time under an applied stress—accelerates with increasing temperature. This means, then, in the use of metals at elevated temperatures, that the design stress be chosen so that the deformation shall not exceed a limiting amount for the contemplated service life. Moreover, the possibility of fracture is ever-present due to the various structure instabilities that can arise with time within the metal itself—instabilities such as graphitization, spheroidization, and carbide migration to name a few. The extrapolation of short-time stress-rupture tests to determine turbine life at elevated temperatures is an exacting science that has come of age only in the past decade.

12 per cent chromium stainless iron or steel has long been the standard for blading and it continues to be satisfactory for operating temperatures up to 925° F. Above this temperature it is necessary to add 0.8 per cent molybdenum to increase the creep properties. Again, as the temperatures reach 1000°F it has been necessary to search for new materials. Considerable attention is now being devoted to the more complex steel groups, with all indication that the stainless ferritic steels will be utilized. Factors influencing the selection of materials at these elevated temperatures will be covered in succeeding paragraphs.

Bolt steels are another recipient of considerable attention. They must have a high yield point at room temperature as well as good creep properties. Chromium-molybdenum-vanadium bolt steels have proven to be 100-150°F better than chromium-molybdenum steels for the same creep rate at a given stress. Bolts when in service are generally not subjected to constant stress but rather to constant strain. As the material creeps, therefore, the elastic strain (and thus the bolt stress) diminishes, eventually decreasing the bolt tension to the extent that the joint must be retightened if leakage is to be prevented.

There is now another factor besides mechanical properties that must be considered when operation at these elevated temperatures is being contemplated: oxidation resistance. This effect probably does more to restrict high temperature operation than any of the other metallurgical instabilities previously mentioned. Oxidation or scaling of the metal occurs by a process of diffusion of oxygen inward and the alloying elements outward. Within the temperature range of the carbon-moly and chrome-moly steels the resistance to oxidation is completely adequate, and thus the use of these particular alloys is limited by their mechanical properties. As we enter the temperature range of the molybdenum-vanadium and the chromium-molybdenum-vanadium steels, however, we find the mechanical properties considerably improved but no appreciable change in the material's resistance to oxidation. At this point we must ascertain whether the upper limit of temperature for which these steels are suitable is to be determined by oxidation resistance or creep properties.

Considering oxidation resistance it can be said that all the low alloy steels are unsuitable at temperatures above 1000-1025° F. When the steels are required to withstand oxidation and stress for long periods above this temperature we must use austenitic steels of the 18 per cent chromium, 12 per cent nickel, and 1 per cent niobium type. In addition to providing increased oxidation resistance, it has been found that the face-centered cubic structure of austenite is considerably more creep resistant than the body-centered cubic structure of the ferritic steels. But now further complications enter the picture. The use of austentitic steels is objectionable

for many reasons: they are costly to begin with, but, moreover, they are difficult to cast and forge, and are not readily machined. The control of clearances is difficult due to their high coefficient of expansion. At room temperature the yield point is low, and, in addition, a low thermal conductivity gives rise to high thermal stresses. For these reasons considerable attention is now being devoted to the development of 6 per cent and 12 per cent chromium ferritic steels, alloying them with such elements as niobium, vanadium, and titanium to give them high creep resistance. In such a way, then, the use of austenitic steels with their inherent drawbacks can be "postponed" until operating temperatures in excess of 1150° F are deemed practicable.

WELDING PROBLEMS

While essentially satisfactory operation has been obtained with 1050° F units employing austenitic stainless steels, cracking has occurred in and adjacent to the welds in a relatively greater degree than has been experienced with the ferritic steels. The actual cause cannot be pin-pointed, but is believed the result of three factors acting either in combination or singly; viz, a greater notch sensitivity of the austenitic steels, a slower relaxation of residual welding stresses, and/or excessive thermal-expansion stresses. In addition, examination of a number of these welds has shown that their ductility decreases with time at the operating temperature due to a sigma phase formation on the deposit itself. While it is true that the effects of notch sensitivity, residual welding stresses, and thermal expansion stresses can be minimized—and perhaps eliminated entirely—by design and erection modifications, the elimination of this sigma phase formation appears to be far more difficult. The probability of graphitization is maximized between 825° F and 1150° F, and appears near many welds at the edge of the heat-affected zone. The addition of chromium as an alloying element and the use of postweld heat treatments presently offer the sole means of combatting this embrittlement. It is factors such as these that must be considered by the manufacturer. Consider the split casing halves as utilized on the turbines of the aircraft carrier *Antietam*: assembled on a facing plate, the halves are mated by bolting and then welding the vertical joint. While primarily aimed at facilitating fabrication, it can be seen that such a practice would be entirely unsuited for a higher temperature operation if only for the reason that it offered another possible entry point for this sigma phase formation.

To digress, the high temperature and pressure piping installations in use today employ only two or three flanged joints, and, in a good many cases, limit the number to one at the boiler outlet and one at the turbine inlet. Boston Naval Shipyard personnel have experienced considerable difficulty applying a satisfactory weld more than once to the same general area should a cut be necessary for repairs or equipment removal. Since the number of times that a weld can be broken and rewelded is obviously limited, increased attention must be given to equipment and piping lay-outs. Newport News apparently is placing attention on the practical aspect of repairs in her more recent designs. A typical example of this would be the placing of the steam inlet piping connections on the *bottom* halves of the casings, giving the obvious advantage of expediting the opening of casings for repairs and inspections. While the number of casing liftings is extremely limited in a *proven* design, thus relegating this advantage to one of secondary importance, the earlier HP-IP turbines on the *Forrest Sherman* class destroyers have been lifted once and possibly twice in some instances. But here it was necessary to cut the steam lines in order to allow removal of the turbines through the sides of the ships. Design studies must consider factors such as these. Greater accessibility must be provided not only to facilitate repairs, but also to reduce costs—for each of these high pressure welds must be subjected to stringent non-destructive tests.

ROTORS AND STABILITY TESTS

Heat indicating or stability tests for turbine rotors are now more or less routine procedure, and the practice is taking hold in Europe. The rotor forgings are stabilized by heat indication at approximately 1000° F, allowing a change of eccentricity of less than 0.0005 inch from the hot to the cold condition. A.S.T.M. rules are quite definite in the procedure to be followed.

Assuming that the forging is received by the turbine builder from the steel works in the normalized condition, it should be free from internal stresses. At this point there are only two kinds of instability that may occur (See Figure 2). In Case I, when the

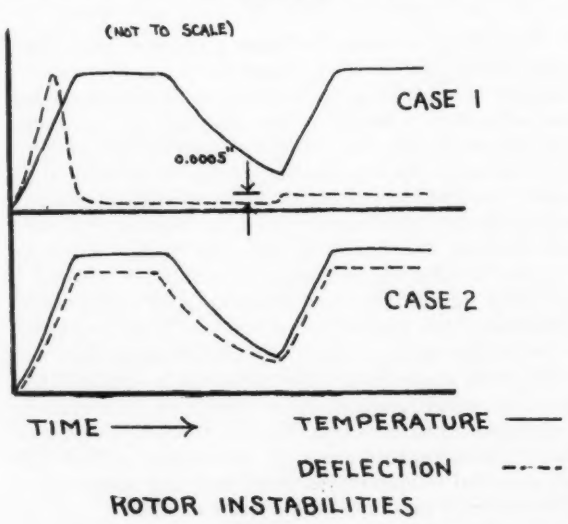


Figure 2.

shaft is heated while rotating slowly, it starts to bow and shows an increase in deflection with an increase in temperature up to a certain point, beyond which the deflection diminishes until the shaft is nearly straight. It remains in this condition while cooling down and shows no repetition of the initial high deflection when heated up a second time. This "once-only" deflection is presumably due to some surface effect—an induced stress—resulting from machining of the shaft and can be rectified by heating the shaft (while slowly rolling) prior to blading it.

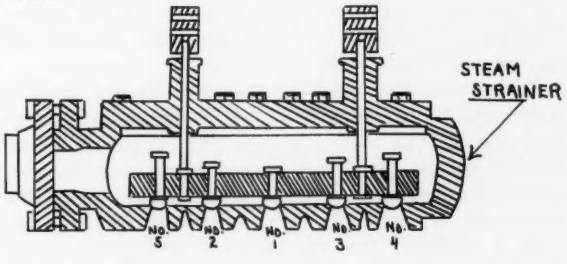
In the second case of instability, the shaft develops a defection increasing in proportion to the temperature and falling to zero as the shaft cools. This same bend is followed each and every time the shaft is heated and cannot be cured by anything the turbine builder can do. This occurrence is extremely rare in the case of carbon steels, but has occurred occasionally with carbon-molybdenum steel shafts. Investigations accredit this to the nonuniformity of forging structure, resulting in a variation in the coefficient of expansion between one side of the shaft and the other. In other words, during normalizing, a pearlitic structure has developed on one side and a bainitic—usually upper bainitic—on the other. This difference in structure is the result of a temperature differential being set up between one side and the other during heating or cooling. With carbon steels it is possible to have a substantial difference in heating or cooling rate on opposite sides of the shaft and still get a pearlitic structure all around. Viewing a series of T-T-T diagrams (the familiar "S" curves) one can readily see how the critical cooling rate varies with the addition of these alloys. Manufacturers usually term these tests as "curing."

As we go to higher steam pressures and temperatures the importance of thermal stress considerations increases. The mean temperature—and hence expansion—of the rotor and casing should increase at the same rate. With turbine clearances based on full-power requirements, it can be seen that clearances can be excessive at lower speeds unless expansion is minimized. This illustrates the importance of the expansion coefficient and the thermal conductivity characteristics of the materials as brought out in an earlier section. The development of the gashed rotor of today was a more or less natural step in the search for smaller clearances. The hollow rotor prevents the higher peripheral speeds, while the use of the solid rotor necessitates larger clearances due to its inherent expansion problem. Thus to minimize tip clearance variation at the various power requirements, and thus increase the efficiency range, the eventual use of the gashed rotor in all new construction utilizing the higher pressures and temperatures is an inevitable one.

CONTROL VALVES

It should now be evident that the turbine designed to operate with a steam temperature of 1050° F is materially different in design from one for use with the lower steam temperatures. While the increase in initial pressure does not present any particular difficulty in the design, the high temperature requires special attention both in design and materials. This applies to the ahead nozzle-control mechanism also. These valves are contained in a forged alloy-steel body which is connected to the individual nozzle chambers by means of pipe bends. One typical design embodies a steam strainer and governor valve manifold. Figure 3 illustrates this. Location of the entire valve proper within the working medium overcomes any adverse effects of differential expansion. The valves open in the consecutive order indicated, depending on when the lift-bar, operated through two vertical stems by a lever arrangement, engages the shoulder of the retaining nuts. In effect, then, the result is the same as the cam-operated nozzle-control valves on the DD 445 and DD 692 class destroyers, only now considerable emphasis has been given the effects of temperature.

Vibration of the valves within the bar-lift is prevented by providing the lower portion of the retaining nuts with a nitrided spherical seat. This requires the nut to slide instead of roll should any tendency to vibrate or spin set in. To date, highly satisfactory results have been found with this arrangement.

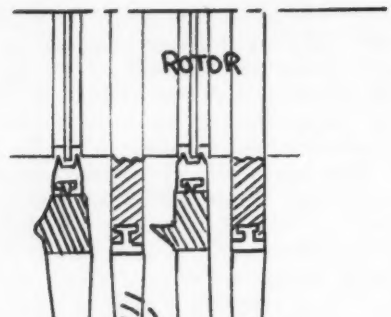


BAR-LIFT TYPE NOZZLE
CONTROL VALVE

Figure 3.

CORROSION-EROSION PROBLEMS

Water droplet erosion can occur in the later stages of the low pressure turbines when the linear blade speed exceeds roughly 900 feet per second and a moisture content of 10 per cent or more is present. Figure 4 illustrates one of the newer methods being used to take care of the moisture precipitated by the temperature and pressure drop, a design engineered by the DeLaval Corporation. Small orifices have been installed all along the lower portion of the casing into which the water drains, eventually passing on and out of the casing. These small orifices allow the drainage to continually drop in pressure as expansion take place, but should not be confused with equalizing holes sometimes found in the turbine wheels of impulse stages—those are drilled in



MOISTURE EXTRACTION DESIGN

Figure 4.

order to equalize the pressure on each side of the wheel which otherwise might cause thrust. This particular arrangement is associated only with the low pressure turbines. Lips take care of the actual drainage, tending to carry off the water thrown off by the rotating wheels.

Protection must still be provided for the blading subjected to the impact forces of the water droplets. One of the methods receiving considerable attention in this country is that of improving the mechanical properties of the base material. By using the same 12 per cent chromium steel blading but with a modified heat treatment in which tempering is in the region of 600°F. an increase in hardness from the conventional 200-240 Brinell to one of 375-400 Brinell results. An alternative method calls for flame hardening the area subjected to these impact forces, but this leaves a heat-effected zone adjacent to the hardened zone which can be of questionable quality.

A second method that appears to be coming into its own is the application of a higher hardness alloyed material made by precision casting or wrought methods by silver brazing it to the surface. This method has been used here and abroad. The major difficulty is being able to produce good fit-ups, as well as the fact that the strip may become detached and cause further damage in the turbine itself. Moreover, the brittleness of the deposit material itself must be considered.

GLANDS AND LABYRINTH PACKING

The practice of installing glands and labyrinth packing to close clearances and then during the initial slow running-in period allowing them to rub to the desired clearances is no longer an accepted practice. There are now sufficient data that realistic gland and labyrinth clearances can be established initially, avoiding this.

Carbon rings, however, continue to be a source of considerable consternation and a turbine with an effective high pressure seal not utilizing them would be most welcome. Efforts are now being made to extend the pressure range of a labyrinth-type packing in an attempt to eliminate the maintenance costs associated with carbons. Anyone with any familiarity with the renewal of carbon rings on the DD 445 and DD 692 class destroyers will appreciate this. It might even be considered a forgotten art. In the case where the fitting of the rings is too tight there results a low speed vibration felt all the way up to the captain's sea chair. It is one thing to allow excessive clearance in such a repair (and to then obtain that distinct and annoying wisp of steam at high speeds), but to "optimize" the repair with minimum clearance is an art on these classes due to the awkward working positions necessary for fitting when a mandrel can't be used.

FEED SYSTEM CONTAMINATION

The entry of water to oil and oil to water are both problems that must be reckoned with, but the latter is definitely the harder to detect and apparently exists or has existed on a good many of our Naval ships, a fact borne out by reports of the various Boards of Inspection and Survey. And, as these higher steam temperatures come in to more general use, the prevention of oil leakage assumes all the more importance. The boiler serves as the collecting chamber in the end; and whether the oil deposits itself in the form of "oil balls" in the mud drum or a thin film over the tube, the end result is a reduction in circulation or heat transfer.

While the turbine oil seal ring in itself is a rather simple design feature, it must be recognized that the oil-drain piping arrangement plays an equally important role in preventing leakage. Considerable difficulty has been experienced on the DD 445 class destroyers due to contamination of the feed system. In one instance the cause was found to be the result of flooding of the forward bearing housing of the low pressure turbine during jacking-over periods, oil leaking along the shaft and being drawn into the feed system through the condenser. It can be shown that, under the condition of constant pressure, the quantity of oil pumped through a turbine's journal bearing can vary by a factor of more than two, depending on the attitude of the bearing. When jacking over the journal rides on the bottom of the bearing, and the quantity of oil pumped through exceeds that passed when operating under load. This was the case here, and lowering the working pressure to 8 psi during jacking-over vice the manufac-

turer's suggested 10-12 psi rectified the condition. This serves as ample testimony that piping designs must be based on stand-by conditions as well as full power requirements. In the early stages, contamination can usually be found on economizer inlets and de-aerating tank baffles; eventually, when sufficiently advanced, it can be detected in the gauge glasses.

On the coupling end of the turbine a means must be provided to prevent windage from the gear case from blowing back into the bearing sump adiacent to the oil baffle, or an additional load will be placed on this baffle. Also, the oil drain system must be designed to prevent gearcase pressure working on the turbine bearings via one of these lines. This is done by admitting turbine oil drains to the main sump below the oil level. The practice of running separate drain lines from coupling-end bearings and the forward bearings now appears to be standard procedure in an effort to limit the "windage leakage" to only one bearing should "malfunctioning" exist.

One of the better designs for the oil baffle incorporates three flinger extensions on the shaft and four points in the oil baffle, one mating each outboard flinger, and the central two straddling the center flinger, thus forming two chambers. The chamber adjacent to the glands drains any possible oil or water from the gland to a sloped drain outside the turbine. The central chamber is vented to the atmosphere and drains through a loop seal to the bearing sump. The chamber adjacent to the bearing drains to the bearing sump.

CONCLUSION

It has not been the intention of the author to outline a definite design criterion but rather to set down a few of the techniques in use today, along with the practical considerations that must be made. It is realized that such practical aspects of turbine operation as casing distortion and turbine vibration have been omitted. The lighting-off phase in any turbine operation is definitely one of the more critical, and inattention to a sufficient "warming-through" period can result in a kind of "starting-cycle fatigue" resulting in casing or rotor distortion. All too often in a discussion one hears of improper warming-up of the spindle, but ever so little concern extended the thick casing flanges and their possible low rate of heat conduction. Regarding vibration, considerable investigation is now being applied to the failure of the blading in the seventh stage of the HP-IP (Westinghouse) turbines now in use in the new DD 931 class ships. The increased centrifugal forces due to the higher rotative speeds have not been blamed, but, rather, company representatives think that torsional vibrations set up in the shaft could be the cause. If this is the cause, it adds weight to the test facilities now being utilized by the English Navy where complete machinery installations—*including* propeller shafting—undergo rigid tests prior to acceptance and installation. Quite different from piece-meal acceptance runs.

It can be concluded, then, that in spite of the advanced design of the current series of turbines, the problems are not altogether new, but rather that new techniques must be developed to meet them.

BIBLIOGRAPHY

1. "Diesel-Electric Drive vs. Geared Steam Turbine Operation for Supertankers," T. O. Lisle, March 1955, *ASNE*.
2. "Factors Influencing the Continuing Development of Steam Turbines," F. Dolan, Oct. 1954, *ASNE*.
3. "The Influence of Thermal Effects on the Maneuverability of Marine Turbine Machinery," B. J. Terrel, *North-East Coast Eng. & Shipbuilders*, Nov. 1953.
4. "Welding Type 347 Stainless Steel for 1100° F Turbine Operation," R. M. Curran and A. W. Rankin, March 1955, *ASNE*.
5. "Symposium on Turbine Operating Experience"; Part 1 "Turbine Operating Experience," A. D. Hall; Part 2 "Some Operating Experience with Westinghouse Marine Turbines," H. Anderson; Part 3 "Corrosion-Erosion Problems in Steam Turbine Operation," F. H. Pennell; Part 4 "Turbine Operating Experience," J. R. Kane; Part 5 "Turbine Operating Experience," A. D. Somes, *SNAME*, Nov. 1954.
6. "Marine Machinery Breakdowns," J. H. Milton, *North-East Coast Eng. & Shipbuilders*, April, 1957.
7. "Recent Naval Steam Plant Design," Cdr. C. H. Meigs, *SNAME*, Nov. 1954.
8. "Naval Turbines," *U. S. Naval Institute*, 1950.
9. "Metallurgy and Metallurgical Engineering Series," Williams and Homerberg-1948.
10. "Physical Metallurgy for Engineers," Clark and Varney, 1952.
11. *Am. Standards for Testing Materials*, 1957.
12. "Modern Marine Engineer's Manual," Vol. 1, Osborne.
13. "Steam Turbine Inlet Valve, Model Tests on," J. H. Potter, *ASNE*, 1955.
14. "Marine Engineering," Vol. 1, Seward, 1955.
15. Class notes, courses 13.75 and 13.76, Cdr. Thornbury, USN, MIT.

Fusion welding processes require an effective means of excluding atmospheric gases, particularly oxygen, from the molten pool of metal at the weld juncture. Organic substances, which form gases at the arc temperature, are used to coat electric welding rod, a technique which effectively shields the molten weld metal when steel is being fabricated. However, coated electrodes are normally not sufficient where light alloys are concerned.

Argon has many properties which commend it as a weld shielding gas. It is chemically inert and it does not tend to dissolve in molten metals. It is 30 per cent heavier than air, which aids it in displacing air in the vicinity of the arc. It enhances the stability of the arc, both with d.c. and a.c. currents. It requires less voltage for a given current flow across the arc.

Two basic processes for its use in welding non-ferrous metals, light alloys, and steels, are the tungsten inert-gas process, and the metal inert-gas process. In the former, the arc is formed between the work piece and a non-consumable tungsten electrode, through which a stream of argon flows to surround the arc. Filler metal is added manually or mechanically. In the latter, the arc is formed directly between the filler metal and the work piece. Argon is supplied separately, usually through the electrode holder.

Advantages of the shielded-arc method are a narrow heat-affected zone; high welding speed; minimum chemical and physical changes in the heat-affected zone; ease of producing sound welds without special training.

—from BROWN BOVERI REVIEW
March 1959

The two major means of measurement of the distance from the earth to the sun, known as the "astronomical unit," depend upon observation of the asteroid, Eros. The values differ by 89,000 miles, indicating an uncertainty of at least one part in 20,000 in the correct distance. Because of the importance of this distance in space technology, a more precise determination is needed. A technique has been developed based on use of the radio telescope to observe the spectral shift in hydrogen radio emissions passing through the atmosphere of a star. This will involve measuring the frequency of absorbed hydrogen radiation in a given radio star at a time when the earth approaches it directly, and again six months later when the relative motion of the earth is directly away from the star. This frequency shift will permit accurate determination of the velocity of the earth which, taking into account the time between observations, will allow an exact determination of the earth's orbit. This is expected to permit calculation of the astronomical unit within a 300 mile accuracy.

—from SCIENCE NEWSLETTER
August 1959

CDR. B. F. SEEGER, USN and ROGER H. LAPP

WATER INJECTION: A NEW PROTECTIVE SYSTEM FOR MISSILE MAGAZINES

THE AUTHORS

Commander B. F. Seeger graduated from the U. S. Naval Academy in 1943 and received the degree of Naval Engineer from the Massachusetts Institute of Technology in 1950. An Engineering Duty Officer, he recently completed a tour as Assistant Branch Head for Damage Control and Fire Fighting in the Damage Control, Ship Salvage and Personnel Protection Branch of the Bureau of Ships and is presently on duty at the San Francisco Naval Shipyard. Previous assignments include: Engineer Officer USS HUGH PURVIS *(DD-709) and USS* POWER *(DD-839); Charleston Naval Shipyard; Ship Repair Facility, Guam; Naval Research Laboratory.*

Roger H. Lapp is a graduate in Engineering from the University of Iowa in 1943. Mr. Lapp did research with the Elliott Co. in support of the Manhattan Project and the development of maritime gas turbines. With the Ford Motor Co., 1952-54, he designed a pilot gas turbine research laboratory. He is presently with Johns Hopkins University, The Applied Physics Laboratory and has led the safety research project for the Navy's TERRIER *and* TARTAR *guided missiles.*

In April of 1959 the USS *Canberra* completed checking and placed in service a missile water injection system designed to increase the damage resistance of her surface-to-air TERRIER missile installation. Since such a water injection system will probably be installed in many future ships having missiles aboard, it is of interest to describe the installation and how it functions and to explore its limitations and capabilities.

First, consider the situation which gives rise to such an installation. Why is a water injection system considered necessary and desirable for missile magazines as opposed to conventional gun ammunition magazines? Early in the design of missile installations it became apparent that several vital departures from conventional magazine arrangements would be required. The concept of readiness for anti-aircraft action, coupled with the large size of a complete missile, required that the magazine extend into a relatively exposed topside location on the ship. The higher location and large size of the magazine limited the degree of ballistic protection which could be afforded. It was necessary to accept the fact that this large amount of explosive material, both propellant and warhead, be exposed topside. This exposure makes it possible that minor initial damage, such as might be caused by a near miss or a small caliber hit, could result in penetration and ignition of some portion of one or more missiles. In addition, the provision of automatic missile handling equipment capable of rapidly moving missiles into position for firing has required relaxation of the time-honored concepts of maintaining magazines almost free of electrical and hydraulic machinery.

Readiness requirements have dictated the mixing of different flammable, explosive, and fusing components in one magazine space to a degree which had never been previously considered acceptable. Finally, it is necessary to actually apply electrical power to the missile in order to obtain a fully ready condition.

Early tests on the TERRIER missile confirmed the fear that ignition of either the booster rocket or the sustainer rocket would chain-ignite adjacent units. The high temperature and pressure resulting from one burning booster is graphically shown in Figure 1. This photograph was taken one-half second after ignition of a single TERRIER booster in a vented steel sphere with a free volume which stimulates the CAG missile magazine. If a minor casualty is not to result in loss of the ship, means of stopping the chain ignition, which could result in consumption of the entire powder charge of the magazine, must be provided.

Photograph by David Taylor Model Basin.

Figure 1. A Vented Steel Sphere with a Free Volume which Simulates the CAG Missile Magazine. Photograph taken one-half second after igniting one TERRIER Booster.

From the initial safety test program sponsored by the Bureau of Ordnance and conducted by the Applied Physics Laboratory, The Johns Hopkins University, at the Naval Proving Ground, Dahlgren, Virginia, it was determined that the provision of suitable baffling between the sustainer rocket and booster rocket of the TERRIER missile would greatly reduce the probability of a burning sustainer chain-igniting its own or adjacent boosters. The next series of tests demonstrated rather dramatically that a burning booster would chain-ignite adjacently stowed booster rockets within seconds. This would shortly involve all missiles in the magazine including their warheads. At this point an investigation was begun of methods which might be used to extinguish a booster before chain ignition could occur. Initial tests on the TERRIER missile showed that automatic water injection could in many cases quickly extinguish a burning booster. In most instances where a booster was not actually extinguished by the first few gallons of injected water, the burning rate was slowed to the point that the danger of chain-igniting adjacent units was materially reduced.

The water injection system was initially called a quench system, the name being derived from the mechanism by which an exothermic chemical reaction is quenched by removing heat faster than it is generated. The task appears simple when you demonstrate that a pencil-size stick of propellant flaming at one end is immediately extinguished by plunging the fire into a thimbleful of water. The simplicity of the mechanism becomes doubtful when the end of a similar propellant stick is cracked or slotted with a razor; this sample cannot be reliably extinguished, even if dunked into a barrel of water.

TERRIER propellant burns reliably with two modes, one with flame and one without flame; the latter is referred to as fizz burning. The fizz mode is slightly exothermic and can exist alone at a low temperature; the flame mode is very exothermic, exists on the products of the fizz mode, and requires a high temperature. Fizz burning in cracks or crevices is the joker which prevents reliable quenching in the slotted stick of propellant, and thus makes a seemingly simple task very difficult. It can be assumed also that somewhere among the hundreds of square inches of ignitible surface within a rocket this situation will exist, particularly if a fragment has caused its ignition.

Let us examine a fire started by a fragment which grows bigger until the entire rocket propellant grain is on fire. Likewise, after the fire is detected and water is injected into the rocket's only opening, the exhaust nozzle, the wetted surface area of propellant becomes greater until, hopefully, the entire inner surface of the propellant is wet and quenched. Here we throw in the old adage—the one there first with the most, controls the situation. If the water can be applied to all burning surfaces, the fire will be extinguished. If the rocket progresses to a burning rate sufficient to create a sonic exhaust jet, the water cannot enter the rocket. For example, one could slowly push a steel rod into a jet of gas moving at the speed of sound, but one could not push a stream of water into the jet because the water has no rigidity. A successful quench can be obtained only if water is injected early and can reach all surfaces which are burning. Accordingly, a high speed water stream and a fast fire detector are required.

The fire detector must transduce one of the products of fire (such as heat, light, pressure, ionization, gases of combustion, or noise), or use some other device like a breakwire grid, which will detect either the fragments or inadvertent electrical ignition.

The shock pressure detector (see Figure 2) is the simplest of several types of fire detectors which have been considered. Originally conceived by engi-

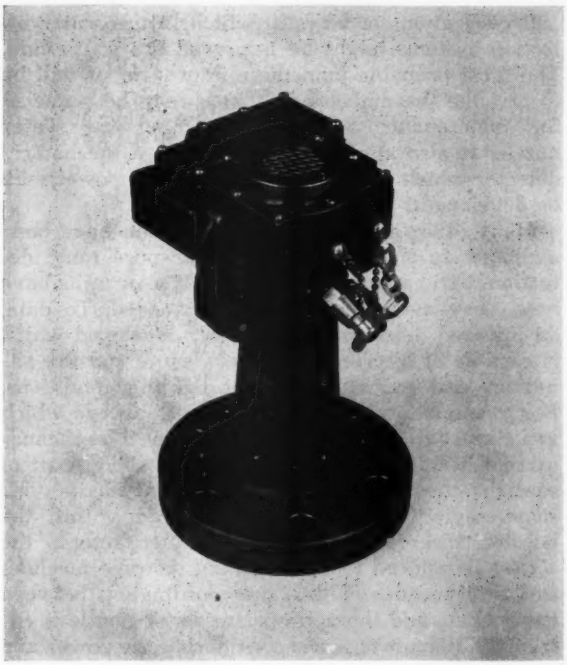


Figure 2. Water Injection Nozzle for TERRIER Missile Magazine USS Canberra CAG-2.

neers of the Applied Physics Laboratory, the production type detectors aboard the USS *Canberra* represent a cooperative effort of personnel of that Laboratory, the Naval Proving Ground at Dahlgren, Virginia, the Bureau of Ordnance, the Bureau of Ships, and the Bureau of Ships' development contractor, the Grinnell Company, Inc.

Figure 3 shows a schematic diagram of the system installed on the USS *Canberra*. It consists of an extension of the firemain feeding a combination detector-nozzle under each missile index position. Through use of suitable check valves, the water accumulator and that portion of the system which is downstream of the check valve may be charged to greater than firemain pressure and kept filled with fresh water to reduce maintenance problems. The water accumulator tank, with its attached pressurized air flask, rides on the system as a surge tank and is designed to provide water during the period after a detector nozzle has opened and before additional fire pumps can be automatically brought up to speed.

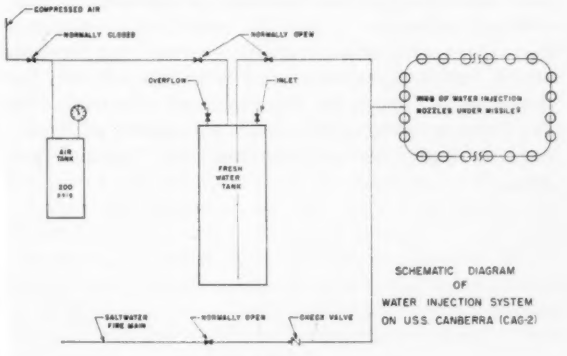


Figure 3.

In actual operation the sequence of events would be as follows: ignition of the booster or booster igniter causes pressure build-up within the booster which dislodges the booster nozzle closure and directs a shock pressure wave to the top of the detector. The shock pressure wave causes movement of the metal diaphragm (see Figure 4) which closes the self-holding switch located directly beneath. Closing of this switch completes a battery circuit and fires the explosive primer located in a cavity covered by the nozzle cap restraining latch. Firing of the primer releases the latch and allows the water to rotate the cap out of the stream path in a few milliseconds. Water is then continuously injected into the booster rocket until the system is secured. The initial flow of water is from the accumulator tank and this flow trips a switch which automatically starts an additional fire pump. This pump should be up to speed and maintaining firemain pressure by the time that the accumulator pressure drops below 70 psi.

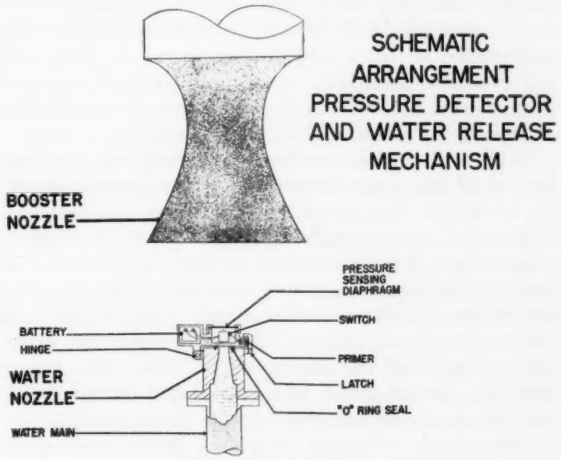


Figure 4.

Actual TERRIER booster firing tests equipped for water injection have demonstrated a high probability that any non-propulsive booster which might be inadvertently electrically fired will be extinguished before more than a very minor portion of the grain has been consumed. Two factors contribute to the efficient functioning of the system under these conditions. First, the firing of the igniter produces a sharp pressure wave prior to propellant ignition and the detector is triggered within milliseconds. Second, this type of ignition leaves an intact grain which can be readily reached and quenched by the injected water.

In the event that a booster motor is ignited by penetration of a hot fragment, actual extinguishment becomes more difficult. In tests in which the booster was ignited by a 20 mm projectile (chosen to represent fragment ignition), there was an inherent delay while the pressure built up in the booster, and several seconds elapsed before detection by pressure shock was possible. The entry of a fragment also leaves a hole in the grain which may or may not be readily reached by the water. However, in many of the fragment ignition tests which have been conducted, the water injection system apparently reduced the burning rate to the point that chain ignition of adjacent units might be prevented.

It is concluded from such tests that the USS *Canberra's* water injection system is worth the cost in money, maintenance, and weight, provided that the possibility of accidental actuation of one of the water nozzles is very remote. In common with conventional sprinkler sytems, the water injection system may inflict extensive water damage if triggered when not actually required; flooding of a missile magazine would require major repairs and constitute a serious loss of tactical readiness.

To guard against inadvertent detector operation and water release under shock conditions, the prototype detectors were subjected to the high shock tests specified in Military Specification Mil-S-901, and passed without inadvertent operation. This testing consists essentially of dropping a four hundred pound steel block from five feet onto an anvil plate to which the detector has been secured.

A second type of inadvertent operation, the triggering of too many detectors by one burning booster, must also be prevented.

A ship could supply firemain water to a given percentage of its connected outlets. With water injection, no ship would ever be able to supply all of the water injection nozzles simultaneously, for their combined orifice area equals many times the cross-section area of the firemain. It is for this reason that the investigation of sympathetic detection has played an important role in this development.

The shock pressure detectors have been made progressively less sensitive than they were in original tests. Fortunately, the magnitude of the pressure pulse issuing from an ignited booster rocket nozzle rapidly decreases with distance from the source. This allows the use of a shock pressure detector which is sensitive enough to function correctly under a burning booster and will not necessarily be triggered if located several missile positions away.

Investigations of ways in which future water injection systems might be improved are continuing. The most probable immediate improvement will be to arrange the detector so that it may be removed for maintenance without unlatching the water nozzle. It also appears probable that a mechanical detector which does not require battery power may be developed.

Many other aspects of water injection have been explored. In an attempt to achieve more rapid detection, various types of infrared detector units have been developed and preliminarily tested. To date. an infrared detector has not been developed which is capable of discriminating between actual fire situations and expected ambient lighting conditions. For example, an infrared device with an eye which looks into each rocket could be triggered by a hand-carried flashlight or by an occasional stray shaft of sunlight through the launcher loading doors. The same device cannot be easily placed within the booster rocket for these controlling factors: the rocket is secured to a translating stowage mechanism, and because of this, the coordination between the rockets and the appropriate water nozzle is extremely difficult to solve, considering the power and signal wires required for the infrared detector. Infrared detectors external to the rocket are also potentially subject to sympathetic detection. For example, all detectors within a magazine might detect the same bright flash even though only one rocket is on fire.

After water injection starts, it has been found that cycling the water to a scheduled program of water ON 30 seconds and water OFF 5 seconds is more likely to give an early quench than continuous water injection. Cycling created a psychological barrier to acceptance by many observers since such action gave the rocket an opportunity to flame out of control every 35 seconds.

A mechanism to automatically cycle the water has been built, but is presently considered too complex to justify shipboard installation. Complexity was also a problem in the use of wetting agents. Although wetting agents have been tested, the problems associated with preventing corrosion and providing proper proportioning for continuous flow appear to outweight the possible advantages.

Water injection cannot be considered a panacea. It is successful only if chain ignition and warhead action can be prevented and tests have shown that this cannot always be accomplished. As with other fire fighting systems which are commonly utilized, it reduces but does not eliminate the possibility of loss.

"MARINE ENGINEERING/LOG"

ORGANIC REACTOR EYED FOR NUCLEAR T-7

ACKNOWLEDGEMENT

The author of this article is Edward G. Lowell, Applications Engineer, Atomics International, a Division of North American Aviation, Inc. It was published in the August 1959 edition of "Marine Engineering/Log."

INTEREST IN THE Organic Reactor for marine power was stimulated recently when the Atomic Energy Commission announced its latest study of a 60,000-dwt, nuclear-powered T-7 tanker. Applying the most advanced Organic Reactor (OMR) technology to the study, the AEC's contractor, Atomics International, developed the preliminary design for a 30,000-shp main unit capable of driving the ship at a speed of nearly 18 knots.

The study showed the reactor to be well adapted to marine service with respect to weight and space requirements, safety, ease of operation and rapid control. With respect to economics, the design also gave some indication of closing the gap between conventional and nuclear ship costs. In assumed service between the Persian Gulf and the East Coast, the cost per ton of cargo was calculated to be about 20 per cent above conventional for the first OMR-powered T-7. The study also indicated reductions in both capital cost and fuel cost which could bring this figure down to a competitive level for subsequent ships.

Other developments of the past year have also focused attention on the organic reactor as a nuclear power source for marine service. In August 1958, a survey of the application of nuclear power to marine propulsion was completed for the Maritime Administration and the AEC by a group of independent organizations in related fields.

After a comprehensive study of a number of reactor concepts, American Standard Atomic Energy Division, Matson Lines, Todd Shipyards and Stanford Research Institute, in their report "Economics of Nuclear and Conventional Merchant Ships," found the OMR to be "the most attractive nuclear propulsion system for the near future." Early this year, the system received additional endorsement when West Germany's Kernenergie* awarded an OMR study and development contract to INTERATOM.** The study program calls for the design of a prototype OMR power plant which would be the forerunner of larger propulsion units. The contract is expected to culminate in the construction of a 10,000-shp experimental unit to be located ashore or installed in an existing hull. The initial application of the organic reactor to marine propulsion was a conceptual design of a 38,000-DWT, 20,000-SHP tanker completed for the Atomic Energy Commission during 1957, by Atomics International and J. J. Henry & Co.

ORGANIC REACTOR CONCEPT

The organic reactor is a relatively simple reactor concept, in many ways similar to the pressurized-

*Gesellschaft fuer Kernenergie in Schiffbau und Schiffahrt (Company for Atomic Powered Ship Development) located in Hamburg, Germany. This firm is composed of German shipowners and shipbuilders and receives support from the West German Federal Government and the four North German coast States.

**INTERATOM, a West German reactor manufacturer, is a jointly owned company formed in December 1957, by Atomics International and Demag AG of West Germany.

water system. Both types are heterogeneous, solid-fueled reactors in which a single liquid is used as both neutron moderator and heat-transfer medium. As the moderator, the liquid surrounds the fuel, providing a medium in which a certain amount of energy is absorbed from the fast-moving neutrons to permit better control of the nuclear reaction. In its second function, the liquid transfers the heat produced by nuclear reaction in the fuel elements to separate exchanger-type boilers where steam is generated. The principal feature of the organic reactor is the substitution of a synthetic hydrocarbon liquid for the highly purified water used in the pressurized-water system.

The use of an organic liquid as moderator and heat-transfer medium produces a reactor with many attractive features:

The high boiling-point range (700°-800°F) of the organic permits operation of the nuclear system at a significantly lower pressure (100 psig) than the water systems (1,000-2,000 psig). In addition to the safety resulting from the lower stored energy, low-pressure operation allows the use of simpler mechanical components and much lighter reactor vessels, piping, and associated equipment.

The non-corrosive character of the organic, even at elevated temperatures, permits the use of low-cost, easily fabricated materials in the nuclear system. It is relatively inert to both carbon steel and aluminum, as well as to metallic uranium and the uranium compounds considered most promising for fuel. This permits savings in construction cost and the use of fuel combinations not practical for water reactors.

The organic is only midly activated by exposure to neutrons in the reactor core. As a result of low induced-activity levels in the organic system, much of the nuclear plant equipment is accessible for inspection and maintenance during operation.

30,000-SHP PROPULSION SYSTEM

The preliminary design developed during the recent study confirmed that the OMR is a compact, lightweight, relatively simple unit promising ease of operation combined with safety. Figure 1 is a simplified diagram of the nuclear-steam system. The organic coolant leaves the reactor at a temperature of 675°F, passes through two steam generators, and returns to the reactor at 620°F. Circulation is maintained by two centrifugal pumps with a total pumping capacity of 26,000 gpm. The primary coolant system is designed for 150 psig and operates at 34 psig. Steam at 450 psig and 650°F. is produced at a total rate of 250,000 lb./hr. by the two steam generators, each consisting of an evaporator, steam separator and superheater.

Several reactor auxiliary systems also are required. A fractionation unit continuously purifies a small sidestream of organic removing high-boiling compounds formed by irradiation of the material during its passage through the core. These compounds are completely soluble in the coolant, but if allowed to accumulate above 30 per cent, begin to reduce heat transfer. A gas-disposal and pressurization unit removes any gases formed in the coolant and keeps the system at the desired pressure.

Afterglow heat from the reactor after shutdown is removed by an auxiliary cooling system. A second auxiliary system cools the reactor's primary shield.

FUEL ELEMENTS

The reactor is fueled with uranium dioxide in rod-type elements. Each rod is a 60-in. finned tube of aluminum powder metal (APM), filled with pellets of compacted UO_2 powder, 0.33 in. in diameter by 0.60 in. long. One hundred of these rods, containing a total of 78.6 Kg uranium, are assembled in a 5⅛-in. square stainless steel box. Top and bottom fixtures make the complete element 78 in. long.

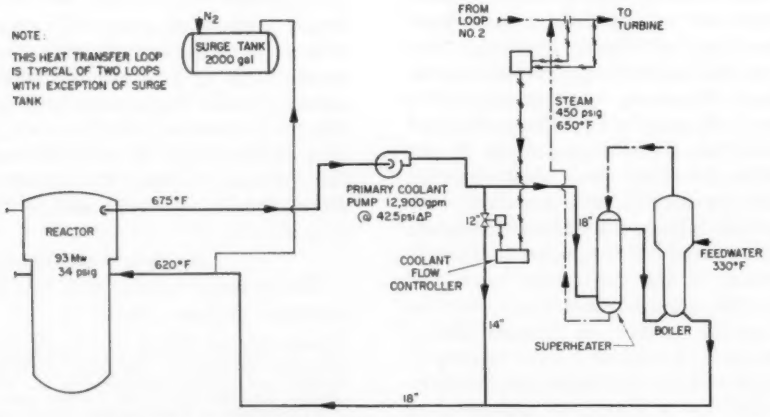


Figure 1. Simplified flow diagram of nuclear steam system.

APM is a rather new aluminum product containing about 7 per cent aluminum oxide which, with modified techniques, can be fabricated somewhat like aluminum. It combines the excellent nuclear properties of aluminum with exceptional strength at elevated temperatures. The finned tubes are extruded. After filling with fuel materials, the tube ends are sealed with welded plugs.

This reactor requires a total of 88 such elements containing 6850 Kg of uranim enriched to a U-235 content of 3.7 per cent. Based on an anticipated average allowable exposure of 14,000 megawatt days per metric ton of uranium, and a use-factor of 85 per cent, the core would require refueling every 16 months. This would be accomplished in about six days with a refueling barge.

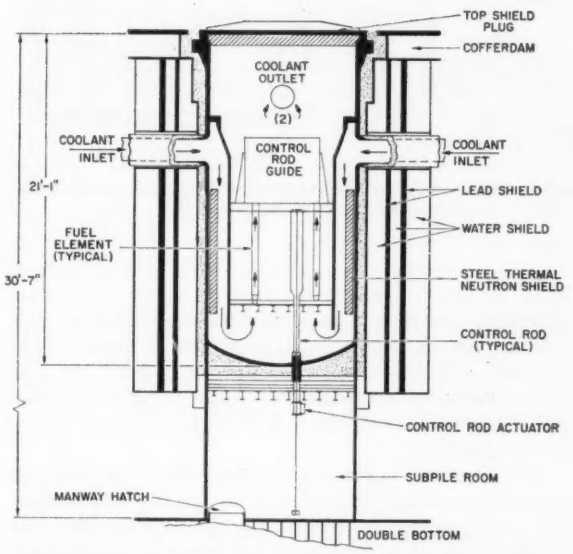


Figure 2. Cross Section shows low-pressure construction of organic reactor.

REACTOR VESSEL

Details of the reactor vessel and its primary shielding are shown in Figure 2. The reactor vessel is a vertical cylinder 9.25 ft. in diameter and 22 ft. high, designed for 350 psig at 750°F. Made of Type SA-204, Grade B, steel (like most of the heat transfer equipment), it has a shell thickness of one in. It is closed with a reinforced flat head, bolted to the top flange. The reactor vessel is surrounded by a primary shield composed of several radiation absorbing regions. These include two layers of lead totaling 6 in., 3 ft. of borated water, and several concentric steel tanks to provide structural support and separation. Diameter of the outermost shield tank is 18 ft. 6 in.

CONTROL

Dual-purpose control and safety rods are provided. These are of cruciform shape and occupy space between the fuel elements. The control rods enter the reactor through the bottom head and are pushed up through the core. For emergency shutdown, the magnetic clutches holding the control rods to the actuators are de-energized, and the rods fall back into the core, assisted by spring motors for initial acceleration.

Load-following controls provide automatic response to power demands ranging from 10 to 120 per cent of full load. Under emergency conditions, load is dropped almost instantaneously by dumping steam to the condenser and by releasing excess steam through safety valves. Emergency increases in power are effected by the use of energy stored in the steam and in the organic, simultaneously lowering average reactor temperature. Having a negative temperature coefficient of reactivity, the reactor immediately responds with an automatic increase in power, necessitating very little control rod regulation. Figure 3 shows the transient plant performance during an increasing load change from 20 to 80 per cent full power at the rate of 10 per cent per second. Opening of the turbine throttle-valves produces a slight drop in steam pressure. This automatically calls for a closing of the coolant by-pass valve and increased flow through the steam generator.

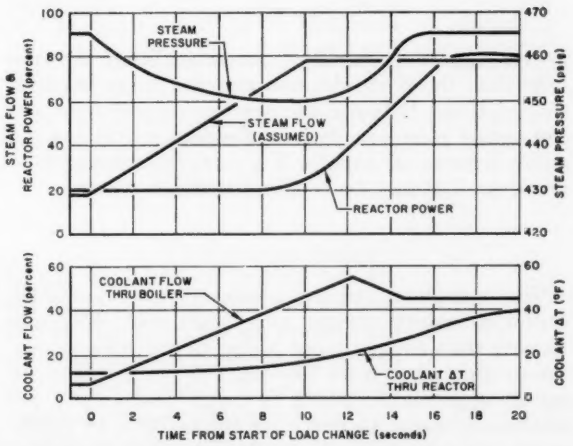


Figure 3. Transient-operation curves illustrate organic reactor's rapid response to load increase.

PLANT ARRANGEMENTS

The general arrangement of the ship's nuclear equipment is shown in Figure 4. The reactor occupies the compartment between the engine room and the cargo-pump room. With the reactor operating at low pressure and at a temperature below the atmospheric boiling point of the coolant, containment has been made an inherent part of the reactor compartment design.

The entire reactor compartment is shielded. The shielding above the reactor consists of 3½ in. of steel plus two ft. of water in a closed tank. On two sides and in front of the reactor compartment are cofferdams

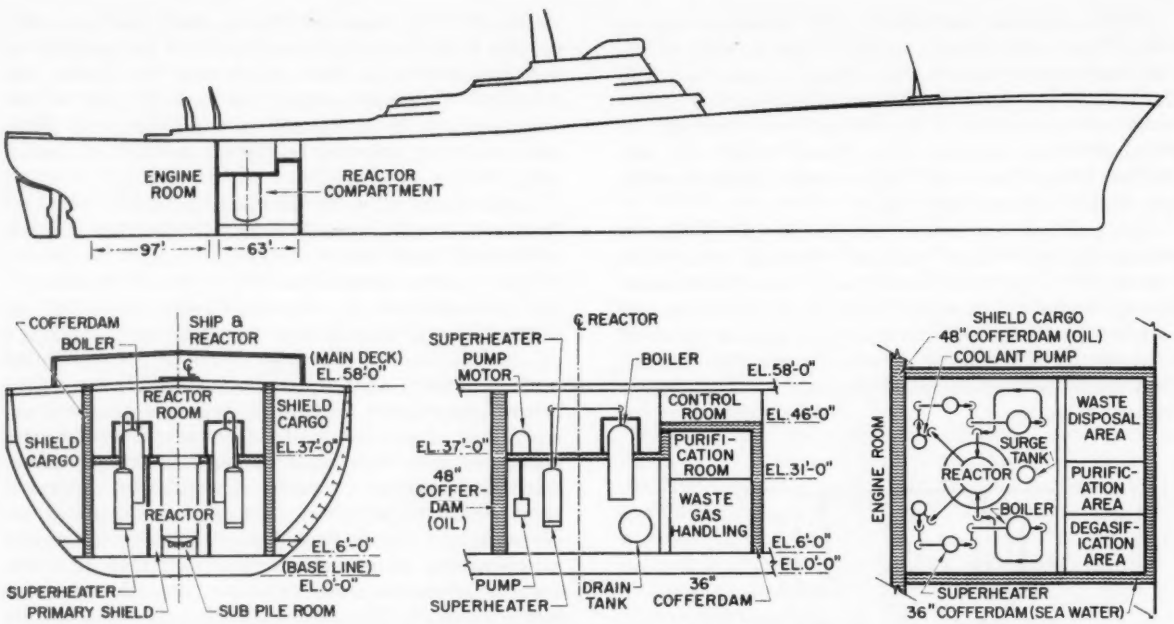


Figure 4. Arrangement of Organic Reactor in 60,000-dwt tanker is shown in longitudinal section (top). Other views are (L to R): Transverse section through reactor, longitudinal section through reactor and plan view at elevation 44 ft. 0 in.

providing a 36-in. shield of sea water. When the ship is loaded, these are drained and the cargo supplies the shielding. Between the reactor compartment and the engine room is a 48-in. cofferdam containing the ship's reserve oil supply. If it becomes necessary to use this oil, it may be replaced with sea water.

CARGO CAPACITY

The complete nuclear steam system, including liquid inventory, weighs only 1,650 tons. Although heavier than conventional boilers of the same power, the nuclear plant frees 5,200 tons of bunker capacity for an appreciable saving in cargo deadweight. An analysis of cargo capacity for the 60,000-dwt OMR-powered tanker and its conventional counterpart is given in Table I for a typical one-way voyage of 12,-000 miles.

This weight advantage gives the nuclear ship an apparent gain in annual cargo capacity of 26,000 tons, or 7 per cent. However, load-line limitations will probably reduce this somewhat as most petroleum cargos originate in tropical waters. Conventional ships thus load to great drafts at the beginning of each payload voyage.

CREW REQUIREMENTS

A crew of 53 men is required for the 60,000-dwt tanker compared to a normal complement of 46 for a similar tanker of American registry. The additional technical men include three junior engineers, one chemical technician, one electronics technician and one health physicist. It is expected that the eight licensed engineers would have the normal training and experience required for a ship of this size, plus additional academic and on-the-job training in reactor operation.

Six reactor operators replace the six firemen normally carried. Their duties are to operate reactor controls and the auxiliaries. They will probably have a minimum of a high school education plus a few years of experience in reactor operation.

ECONOMICS

An economic analysis of the OMR-propelled T-7 indicates that although the first ship of the series will not be competitive with large conventional tankers, its successors could be. Based on an assumed cost of $19 million for a U.S.-built T-7 of conventional design, the nuclear version was estimated to cost $28.5 million. This figure includes all engineering for the nuclear propulsion system, the refueling barge, the preparation of manuals, the necessary crew training, contingency, and escalation through the mid-construction date of November 1961.

Yearly operating costs for this ship are compared with those of a conventional T-7 in Table II. These costs are for U.S.-flag operation between Kuwait and Philadelphia, around the Cape of Good Hope loaded, and through the Suez Canal in ballast.

Considerable savings are expected for future ships in both capital and operating costs. Initial cost of

subsequent ships of the same design should be about $5 million lower, with the principal savings being effected in engineering and contingency. There will also be important construction savings if it is possible to build several subsequent ships at nearly the same time.

Savings in fuel fabrication costs should be reduced substantially for future cores. A 40-per cent decrease is considered quite reasonable for this item and would, in itself, reduce overall fuel cost by about $100,000 per year. This saving, combined with the capital cost improvement suggested above, would bring over-all costs nearly in line. On the Kuwait-Philadelphia run, the calculated cost would be $10.00/ton versus $9.55 for the conventional ship, based on $2.70 fuel oil. A rise in the price of fuel to $3.20/bbl. would make the two equivalent.

FUTURE PROSPECTS

Under the direction of the Atomic Energy Commission, a broad program is underway to improve the technology and economics of the organic reactor for use in central station power plants. At the National Reactor Testing Station a second core containing aluminum-clad fuel elements of recent design has been installed in the Organic Moderated Experiment, an experimental power reactor project being conducted for the AEC by Atomics International. At the company's Canoga Park facilities, extensive field tests are being conducted on components and systems while analytical work continues in many areas. At Piqua, O., Atomics International has started construction of an 11,400-kw nuclear power plant.

In view of the technical and economic promise offered by the T-7 study, it is believed that the design and construction of an OMR marine prototype would be a logical next step in the development program for nuclear-powered merchant ships.

TABLE I—*Tanker Weight Summary—A comparison of the 60,000-dwt OMR-powered tanker and its conventional counterpart (long tons)*

Item	OMR	Conventional
Displacement	77,100	77,100
Light ship	16,260	15,390
Fuel oil, one way plus 12.5 per-cent reserve	.....	5,180
Take-home oil in secondary shield	250	.....
Misc. stores, water, crew	280	280
Cargo capacity, one trip	60,310	56,250
Cargo capacity, annual (6.4 trips/yr.)	386,000	360,000

TABLE II—*Yearly operating cost summary comparing OMR-propelled T-7 with conventional tanker*

Item	OMR Tanker	Conventional Tanker
Crew's wages	$ 500,000.00	$ 435,000.00
Subsistence	47,000.00	40,800.00
Stores and supplies	134,000.00	30,000.00
Maintenance, repair and refueling	215,000.00	180,000.00
Insurance (not inc. nuclear liability)	360,000.00	230,000.00
Port expenses	45,000.00	45,000.00
Overhead and miscellaneous.	53,500.00	53,500.00
Canal tolls	7,700.00	7,700.00
Interest and depreciation	2,285,000.00	1,540,000.00
Total cost excluding fuel	$3,657,200.00	$2,562,000.00
Fuel cost	725,000.00	876,000.00
Total annual operating cost	$4,372,200.00	$3,438,000.00
Long tons of cargo per year	386,000.00	360,000.00
Cost per ton of cargo	11.30	9.55

Vickers Nuclear Engineering, Ltd., a British firm, has conducted a feasibility study of a reactor specially designed for marine use. The reactor uses heavy water as a moderator and dry steam as a coolant. Steam cooling the reactor results in the production of superheated steam at temperatures and pressures corresponding more nearly to modern practice than has been possible with a pressurized water type. Since dry steam enters the reactor, contamination of reactor channels with solid deposits, a problem in BWR design, is avoided. The coolant can be pumped for circulation in its liquid state, an advantage over the gas-cooled reactor proposals. The reactor coolant is turned into steam in a primary steam generator, from which it passes into the reactor. Emerging superheated, a part of it goes to secondary steam generators to produce superheated steam for the turbine. This is condensed and returned through the feed pump to the primary steam generator, in which heat is supplied from the remainder of the steam emerging from the reactor. In this manner, superheated steam is supplied to the turbines at 420 psi and 850°F., using a steam pressure of 620 psi and 970°F. at the reactor outlet.

—from ENGINEERING
June 19, 1959

The keel of the world's biggest cargo vessel, a 106,500 ton oil tanker, was laid at Bethlehem Steel Company's Quincy Shipyard Monday, October 5, 1959, at 8:30 A.M.

This huge tanker, which will fly the American Flag, is being built for Manhattan Tankers Co., Inc., New York, N.Y., one of a group of companies owned and operated by the Greek Shipping magnate, Stavros S. Niarchos. The ship was designed by the Central Technical Department of Bethlehem Steel Company.

She will be able to carry 38,242,000 gallons of oil or more than double the capacity of any one of the six 46,000 ton tankers built at the Quincy Yard during the past two years. On one trip the big ship will transport more than enough petroleum to fill the tanks of 1,911,000 automobiles or 4,777 railroad tank cars.

The tanker will be 940 feet six inches long. She will have a breadth of 132 feet and a depth from her deck to her keel of 67 feet six inches. Fully loaded she will have a draft of 49 feet four inches, too deep to navigate any existing canal in the World.

Powerful twin screws will drive her with a full load at a speed of 17.5 knots. She will be powered by geared turbines capable of developing 39,000 normal shaft horsepower.

In order to make room for building the big tanker, Bethlehem recently extended the 900 foot-long center basin of the Quincy Yard's modern, three-positioned shipbuilding basin by another 65 feet. The ship is scheduled to be delivered to her owners early in 1961.

"PLATINUM METALS REVIEW"

THE PLATINUM RESISTANCE THERMOMETER

ACKNOWLEDGEMENT

Written by Rodney Price, this article was published in the July 1959 edition of "Platinum Metals Review."

THE PLATINUM RESISTANCE THERMOMETER—in which the principle of measurement is the variation in the resistance of a platinum wire as a function of temperature—is generally accepted as the most accurate temperature measuring instrument available. Its sensitivity and reliability are evident from the fact that it was first used in 1928 to define the International Temperature Scale from −190° to 660°C and has thus been the primary international standard for over thirty years. But it has other advantages that find many and increasing applications in industry. It is particularly suitable where measurements are to be made over a relatively narrow range of temperature, where the point of measurement is some distance from the recording instrument, and where there are several measuring points and readings are required at one central instrument panel. In addition to the measurement of elevated temperatures, the platinum resistance thermometer is also finding a number of applications where the accurate determination or control of sub-zero temperatures is needed.

The operation of the resistance thermometer depends upon two characteristics of platinum—first the simple relationship between its resistance and its temperature, and secondly the high purity, stability and reproducibility of the specially prepared platinum employed for this purpose. The requirements of the International Temperature Scale of 1948 for the purity and physical condition of platinum to be used in resistance thermometry are based upon the change in resistance between 0° and 100°C, this range being known as the fundamental interval: the ratio R_{100}/R_0 is required to be greater than 1.3910. British Standard 1904: 1952 on Commercial Platinum Resistance Thermometer Elements calls for a value not less than 1.390.

Any impurity in platinum lowers its temperature coefficient of resistance, and this characteristic of the metal is in fact the most sensitive indication of its purity. For resistance thermometry, therefore, extreme precautions have to be taken not only in the preparation and melting of the platinum but in its subsequent drawing to fine wire in order to maintain an exceptionally high state of purity and complete freedom from contamination during later processing. The special grade of metal prepared, known as JMC Thermopure platinum, consistently gives values greater than 1.3923 for the ratio R_{100}/R_0 and provides a sound basis for the design and construction of accurate and reliable thermometers.

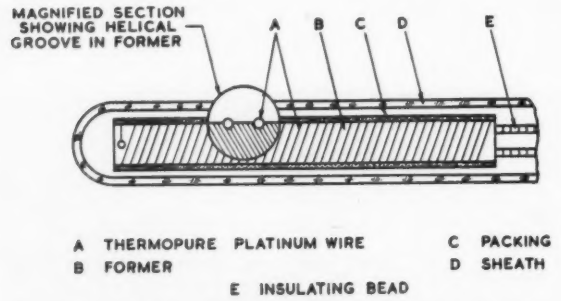


Figure 1. Section of a typical platinum resistance thermometer element, comprising a former of ceramic, glass or metal wound with fine Thermopure platinum wire. The sheath may be made of glass or metal according to the conditions of service.

EARLY HISTORY

The late Professor H. L. Callendar may fairly be regarded as the father of platinum resistance thermometry; the fundamentals of the thermometers in use today are unchanged from those he described in 1887, when as a young research worker of only 23 at the Cavendish Laboratory, Cambridge, he published a paper "On the Practical Measurement of Temperature."[1] This was followed by several other papers which he contributed on the same subject during the next few years.

The resistance thermometer had in fact been introduced by C. W. (later Sir William) Siemens. In a Bakerian lecture to the Royal Society in 1871[2] Siemens had explained the theory of the method and described instruments capable of indicating temperatures up to 1000°C. The advantages of this device were quickly appreciated, and a distinguished committee of the British Association was appointed to test the instruments and report upon them. Their report,[3] published in 1874, disclosed that on heating to temperatures of about 800°C the resistance of the instrument increased continuously and that the platinum wire underwent rapid deterioration.

Callendar became interested in the subject and found that the platinum wires he used did *not* undergo such changes even when subjected to much more severe tests than those applied by the committee. He was able, however, to reproduce the effects they had observed and to show that they were not inherent in the method but were merely incidental to the particular form of instrument on which they had experimented. In particular, he showed that the clay used for the former, or some constituent of it, had attacked the platinum, while the iron protection tube—or even traces of volatile metallic impurities in the iron—had also been responsible. He found that if the wire was properly protected from strain and from contamination the instrument could be made practically free from change of zero, even at very high temperatures. By winding the wire on a thin plate of mica, by fusing platinum connecting wires on to the wire of the coil, and by protecting the element with a hard-glazed porcelain tube, Callendar was able to construct resistance thermometers that completely restored confidence in the instrument.

By 1890 the manufacture of platinum resistance thermometers had begun by the Cambridge Scientific Instrument Company in close collaboration with Professor Callendar and Dr. E. H. Griffiths. Callendar carried out a great deal of research to establish the constancy of the relation between the resistance of a platinum wire and its temperature, and this work, together with his four-lead method of compensation, established the accuracy and reliability of the instrument.

The earliest record of an important use in industry was in 1891, when Sir Robert Mond, working with Callendar, introduced the thermometers at one of his works. In the following year Callendar, working with Professor W. C. Roberts-Austen in the laboratory of the Royal Mint, made the first accurate determination of the melting points of the purest gold and silver then available. In describing this work in a lecture to the Royal Institute Professor Roberts-Austen said "I am satisfied that at temperatures about 1000°C the comparative results afforded by this method are accurate to the tenth of a degree, a result which would certainly have been deemed impossible a year ago."

In 1892 platinum thermometers were used in blast furnaces by Sir Lowthian Bell, while a little later some 65 thermometers and recorders were installed on the annealing furnaces at John Lysaght's sheet steel works at Newport, Monmouthshire. Some of these instruments were in use for as long as 50 years.

In 1900 the Practical Temperature Standards Subcommittee of the British Association agreed:

(1) That a particular sample of platinum wire be selected (Mr. Matthey of Johnson and Matthey had now supplied the Committee with two samples of very pure wire, which on test gave excellent results by the Callendar difference formula).

(2) That Professor Callendar and Mr. Glazebrook be requested to consider further the selection of wires for the construction of a number of platinum resistance thermometers for standard tests.

Six thermometers were accordingly made at the National Physical Laboratory and submitted to a long program of testing by Harker and Chappuis.[4] It was shown that platinum in porcelain thermometers could be heated and cooled between 0° and 1000°C for three months without measurable alteration in the zero of the instruments. This fully established the absolute reliability of the platinum resistance thermometer and confirmed Callendar's orginal claims put forward in his paper in 1887.

In later years other manufactures of scientific instruments also came into the field, and today a wide range of types is available to meet the many varied

conditions encountered in industry. These applications, as will be seen later, include temperature recording or control in the production of liquid oxygen and nitrogen, of chemicals, and of rubber, in the storage of refrigerated meat and fruit and of timber and coal, and in space heating and ventilation.

DESIGN AND CONSTRUCTION

As well as on the very high purity of the special Thermopure platinum wire provided for this purpose, the accuracy and stability of resistance thermometers depend upon the care given to their design and construction.

Great care has to be exercised to avoid contamination of the platinum element and to minimize stressing the wire in order not to reduce its temperature coefficient of resistance.

The ideal mounting for the element wire is one which minimizes the strain caused in the wire by thermal expansion and contraction of the winding former. Callendar devised a former of two strips of mica assembled as a cross with notches cut in the edge of the strips to hold the wire in place. T. S. Sligh,[5] of the U. S. Bureau of Standards, developed this design so that strain is further reduced. In another construction described by C. H. Meyers,[6] also of the Bureau of Standards, the wire is first wound into a fine helix and then this helix is wound on to a former. This produces a compact winding particularly useful for aircraft instruments. J. A. Hall,[7] of the National Physical Laboratory, described a construction in which the element is wound on a fused quartz frame in a hermetically sealed envelope, while his colleague, C. R. Barber,[8] has described a thermometer of very small dimensions in which a formless coil is contained in a fine glass U-tube. The same author has also described a platinum-sheathed 2½-mm diameter thermometer for use at low temperatures.[9]

The selection of suitable protection for the winding depends on the range of temperatures to be measured, the accuracy and life required, and the corrosive nature of the surroundings. Some elements are sealed into glass sheaths; others are protected by mild-steel, brass, copper, stainless-steel or platinum sheaths. For some work, such as refrigerated cargo ships, when speed of response must be sacrificed to protection against corrosion, metal sheaths are completely covered with vulcanized rubber.

To ensure stability it is important to anneal the platinum coil after it has been formed. The International Temperature Scale recommends that standard resistance thermometers should be annealed in air at a temperature higher than the highest temperature at which they are to be used, and in any case at not less than 450°C. R. J. Corruccini,[10] of the National Bureau of Standards, suggests that rapid cooling after annealing is undesirable because it may decrease the value of the temperature coefficient of resistance.

Silk-covered or synthetic-enamelled wire is used to make commercial thermometers to measure low temperatures, but silk covering produces strain in platinum wire, the effect of which upon its resistance characteristics cannot be entirely removed owing to the impossibility of heating the wire to a sufficiently high temperature. British Standard 1904:1952 states that the ratio R_{100}/R_0 for silk-covered wire should be not less than 1.385. The use of a synthetic epoxy-base enamel developed by Johnson Matthey and known as Diamel similarly limits the annealing temperature, but very little strain is caused by the enamelling process and Diamel-covered wire may be used up to 130°C. Values greater than 1.3910 for the ratio R_{100}/R_0 for Diamel-covered Thermopure platinum wire are obtainable.

Although platinum is resistant to a wide range of acids and other reagents, it is desirable to be familiar with the conditions in which the metal is attacked. It rapidly becomes brittle if it is heated in contact with phosphorus, arsenic, antimony, selenium or tellurium. A combination of traces of sulphur and silica or silicates will attack platinum in the presence of carbon, hydrogen or other reducing agent. Platinum is attacked by nearly all molten metals and by their vapors. To prevent contamination of the platinum wire, therefore, all parts of the thermometer should be clean. The selection of a suitable process depends on the materials used in construction, but a typical method is to wash all parts in benzene, boil in dilute nitric acid and wash several times in distilled water. Finally, after assembly and just before annealing, the platinum coil is washed in benzene.

British Standard 1904 recommends that to avoid significant heating of platinum wire being tested in air for use in commercial thermometers, the measuring current should not exceed 2 milliamperes per 0.001 inch of wire diameter. The heating effect of the measuring current depends on the heat conduction of the materials of the thermometer and of it surroundings, and is proportional to the square of the current.

MEASUREMENT OF RESISTANCE

For very accurate temperature measurement, say to 0.001°C, special precaution must naturally be taken to remove every source of possible error. An excellent account of the laboratory procedure involved in this class of work has been given by J. A. Hall[11] and this will not be discussed further here. For a normal commercial accuracy of approximately ±1°C throughout the range of the instrument there is a choice between deflection instruments, null-balance bridges and ratiometers. In deflection instruments the galvanometer in the bridge is calibrated so that the out-of-balance current may be read directly as temperature. The current is proportional to the supply voltage of the bridge, and so either the voltage must be stabilized, or voltage compensation must be provided in the galvanometer movement.

In null-balance instruments the bridge circuit is balanced by manual or automatic adjustment of resistance, usually a slide wire, in one or more arms of the bridge.

A ratiometer is a special type of deflection instrument with a double wound coil which moves in a field whose strength is arranged so that direct indication of temperature results.

Compensation for temperature variations in the leads may be provided by either a three-wire or a four-wire system. In the three-wire system (Figure 2) two leads are in adjacent arms of a bridge, thus cancelling their changes of resistance, while the third lead carries only the energizing current. In the four-wire system a lead equivalent to the element leads and subject to the same ambient temperature variations is put in an adjacent arm of the bridge.

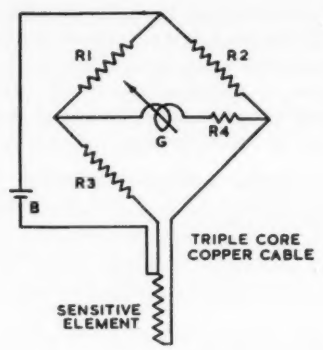


Figure 2. Circuit diagram of a three-wire platinum resistance thermometer and bridge.

DETERMINATION OF TEMPERATURE

The relationship between temperature and the resistance of a platinum resistance thermometer, and H. L. Callendar's method of making the necessary calculations, are given in more detail, together with the tables compiled by G. S. Callendar and F. E. Hoare, in a booklet *Platinum for Resistance Thermometry*[12] which was last revised in September 1958. According to the International Temperature Scale, temperature is related to the resistance of a platinum thermometer according to the following formulae:

For the temperature range from 0° to 630.5°C

$$R_t = R_0(1+At+Bt^2) \quad \ldots\ldots (1)$$

and from −183° to 0°C

$$R_t = R_0[1+At+Bt^2+C(t-100)t^3] \quad \ldots\ldots (2)$$

where R_t and R_0 are the values for the resistance of the thermometer at the temperature of measurement and at 0°C respectively.

The values of R_0, A and B are determined by calibration at the ice, steam and sulphur (444.6°C) points, and that of C by calibration at the boiling point of oxygen (—182.97°C).

For JMC platinum (Table I) the values of the coefficients in equation (2) are:

$$A = 3.98\times10^{-3}$$
$$B = -5.85\times10^{-7}$$
$$C = -4.35\times10^{-12}$$

It was first suggested by Callendar that the arithmetical computation could be greatly reduced by rewriting (1) for the range 0-100°C in the form

$$t = \frac{R_t - R_0}{R_{100} - R_0}100 + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} \quad \ldots\ldots (3)$$

where δ is a constant.

The first term in this expression is the "platinum temperature," derived by considering that the temperature interval between 0° and 100°C can be divided into equal degrees C of temperature by equating temperature to the electrical resistance of a platinum thermometer in this range, and that the relationship can then be extrapolated according to a straight line law. It is denoted by t_{pt}.

TABLE I—*Properties of JMC Thermopure Platinum*

Specific gravity	21.40
Melting point, °C	1769
Resistivity, microhm-centimeters at 0°C	9.81
Mean temperature coefficient of resistance, (0-100°C) per °C α	0.003923
Callendar correction factor, δ	1.493
Van Dusen correction factor, β	0.111
Thermal conductivity, CGS units	0.17
Ultimate tensile strength, tons per square inch (annealed)	9
Elongation, per cent (annealed)	40

Equation (3) may therefore be written

$$t - t_{pt} = \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} \quad \ldots\ldots (4)$$

The correction from degrees platinum to degrees C is most simply ascertained by the use of the tables compiled by Callendar and Hoare.[12]

Equation (3) may also be written

$$t = \frac{1}{\alpha}\left(\frac{R_t}{R_0} - 1\right) + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} \quad \ldots\ldots (5)$$

where α is the mean temperature coefficient of resistance from 0° to 100°C, i.e.

$$\frac{R_{100} - R_0}{100R_0}$$

The relation between the coefficients in equations (5) and (1) is

$$A=\alpha\left(1+\frac{\delta}{100}\right) \qquad \alpha=\ A+100B$$

$$B=-\frac{\alpha\delta}{10^4} \qquad \delta=-\frac{10^4B}{A+100B}$$

For temperatures below 0°C the equation (2) above may be written in the Callendar-Van Dusen form

$$t-t_{pt}=\delta\left(\frac{t}{100}-1\right)\frac{t}{100}+\beta\left(\frac{t}{100}-1\right)\left(\frac{t}{100}\right)^3$$

or

$$t=\frac{1}{\alpha}\left(\frac{R_t}{R_0}-1\right)+\delta\left(\frac{t}{100}-1\right)\frac{t}{100}+\beta\left(\frac{t}{100}-1\right)\left(\frac{t}{100}\right)^3$$

The relation between A, B, α and δ is the same as those above mentioned and the other relations are:

$$C=-\frac{\alpha\beta}{10^8} \text{ and } \beta=-\frac{10^8C}{A+100B}$$

TYPICAL APPLICATIONS

The range of industrial applications of the platinum resistance thermometer, as indicated earlier in this article, is extremely varied and involves the measurement or control of temperatures from the region of −200°C up to 1000°C. Only a relatively few such applications can be described and illustrated here.

In a modern passenger aircraft there may be up to fourteen resistance thermometers. These are required to measure the temperatures of the oil, the fuel, the cabin air, the outside air—for air-speed correction—and the de-icing mats. Base metal thermocouples could be used to measure such temperatures, but would require either control of, or adjustment for, the cold junction temperature, while their low output would necessitate a very sensitive measuring device or some form of amplification. Platinum resistance thermometers fitted with stainless steel sheaths and used in conjunction with ratiometer indicators are therefore preferred.

In power stations resistance thermometers are used, generally with Wheatstone bridges and multi-point indicators, to measure steam, gas and water temperatures.

Two of the illustrations give examples of the wide use of platinum resistance thermometers in the storage, processing and transport of food. Other examples are in the storage of fruit in carbon-dioxide, in dock-side grain silos and in refrigerated cargo ships. Ships carrying refrigerated meat or fruit may have nearly a hundred platinum resistance thermometers connected to multi-point indicators, while in the control of space-heating in large buildings such as movies a number of instruments will be similarly connected to one indicator.

In the chemical industry—one of the largest users of platinum resistance thermometers—the instruments are used both for precise laboratory measurements and for indication, recording and control in process plants throughout the factory.

REFERENCES

1. H. L. Callendar, "On the Practical Measurement of Temperature," *Phil. Trans.*, 1887, 178, 160.
2. C. W. Siemens, "On the Increase of Electrical Resistance in Conductors with Rise of Temperature," *Proc. Roy. Soc.*, 1871, 19, 351.
3. Report of Committee of the British Association on the New Pyrometer of Mr. Siemens, B.A. Reports, 1874, 242.
4. J. A. Harker and P. Chappuis, "Comparison of Platinum and Gas Thermometers," *Phil. Trans.*, 1900, 194, 37.
5. T. S. Sligh, Jr., "Recent Modifications in the Construction of Platinum Resistance Thermometers," *Bur. Standards Sci. Papers*, 1922, 17, 49.
6. C. H. Meyers, "Coiled Filament Resistance Thermometers," *Bur. Standards F. Res.*, 1932, 9, 807-813.
7. J. A. Hall, "A Design for Precision Platinum Resistance Thermometers," *F. Sci. Instruments*, 1933, 10, 4-10.
8. C. R. Barber, "Platinum Resistance Thermometer of Small Dimensions," *F. Sci. Instruments*, 1950, 27, 47-49.
9. C. R. Barber, "A Platinum Resistance Thermometer for Use at Low Temperatures," *F. Sci. Instruments*, 1955, 32, 416-417.
10. R. J. Corruccini, "Annealing of Platinum for Thermometry," *Bur. Standards F. Res.*, 1951, 47, 94-103.
11. J. A. Hall, "The Accurate Measurement of Temperature," *Research*, 1958, 11, 147-151.
12. "Platinum for Resistance Thermometry," Johnson, Matthey & Co., Ltd., London, 1958.

Proper classification of sounds is one of the largest problems involved in SONAR operation. Schools of fish, underwater mountains, wrecks, masses of plankton and kelp, all reflect sound and tend to present a confusing picture to the operator. The provision of accurate service conditions on sonar trainers for the purpose of giving invaluable experience to operators is now being accomplished by high-fidelity tape recordings, in use at SONAR schools at Key West and San Diego.

—from DEFENSE DEPARTMENT NEWS RELEASE

A 2,700,000 gallon per day distilling plant which has been supplying water to the inhabitants of the island of Aruba for about a year is the largest sea-water conversion plant in the world. Steam at 20 psig is supplied to five independent evaporator sets, each having six effects. The yield is nearly five pounds of distillate for each pound of steam supplied. The plant is designed not to exceed 10 ppm of total solids, though operation to date has consistently yielded a plant product well below this. Steam is supplied by two 875 psig, 820°F boilers. The steam is used to generate electrical power through two 7500 KW back-pressure turbo-generator sets before passing to the evaporators. The electricity thus produced as a by-product of the combined plant costs less than 3 mills per kwh.

—from POWER
July 1959

On October 1, 1959, ex-President Herbert Hoover, representing 300,000 members of 18 major engineering societies, broke ground for the 18-story United Engineering Center at United Nations Plaza. Mr. Hoover was assisted by a freshman engineering student from Hawaii, Jerry Fujimoto, representing the engineers of the future.

In remarks just before he turned the first shovel-full of earth at the site of the new Center, Mr. Hoover called the occasion "an event of national importance."

The United Engineering Center, scheduled for completion in mid-1961, will house the headquarters of major engineering societies and joint engineering groups. Their members, Mr. Hoover said, "are the foundation of security in our defense and the increase of the standards of living and comfort for our people." The engineer, Mr. Hoover said, "brings jobs and better homes. This is the high privilege of our profession. The purpose of this great building is to facilitate these goals. It will play a great part in American life. It will serve all mankind," he concluded.

"THE WELDING JOURNAL"

NEW DEVELOPMENTS IN THE WELDING OF ALUMINUM

ACKNOWLEDGEMENT

R. L. Hackman, of Linde Co., Division of Union Carbide Corporation, Newark, New Jersey, is the author of this article. It was presented at the 40th Annual Meeting of the American Welding Society in Chicago, April 6-10, 1959, and published in the July 1959 edition of "The Welding Journal."

INTRODUCTION

THE growth of aluminum as a structural metal for missiles and items such as bridges and pressure vessels is tied very directly to the ability to weld this material. This situation has been greatly helped in recent years by the development of readily weldable aluminum-magnesium alloys which are cold worked and, therefore, do not suffer the same loss in properties as experienced with some of the older precipitation-hardening alloys. In the past, aluminum has been welded with oxyacetylene and oxyhydrogen processes and, to some degree, with covered electrodes. However, with the development of the more modern and faster inert-gas processes, and with the development of resistance spot welding in the aircraft industry, the former methods have largely been abandoned.

Despite their superiority, inert-gas processes have been subject to limitations. In welding aluminum plate, for example, it was once impossible to weld at currents over 400 amp. with the inert-gas consumable-electrode process without having a wild arc develop and disrupt the puddle, thereby resulting in severe oxide folds between weld-metal layers. Although attempts to overcome this situation were partially successful with improved gas shielding, special and rather bulky equipment was required. In similar fashion, it was difficult to develop suitable equipment which could simply and consistently feed small 0.030- to 0.046-in. diameter wire to the arc. This lack hampered efforts to weld very thin aluminum sheet with the inert-gas consumable-electrode process. Likewise, rigid requirements of cleanliness have presented difficulties with respect to efforts to replace the use of rivets and bolts with the inert-gas spot-welding processes.

Against this background of events, recent developments in the welding of aluminum represent significant advances in the art. Specifically, these are as follows: (1) the development of new, simplified welding techniques whereby the inert-gas consumable-electrode process may be used to weld thick plates in fewer passes and at greatly increased speeds; (2) the use of welding wires with less than 3/64 in. diameter for joining light-gage materials by means of the inert-gas consumable-electrode process; (3) extension of inert-gas consumable-electrode spot welding to aluminum along with the application of plug welding to greater than 0.200-in. thick material without the development of cold laps; and (4) the

successful laboratory application of tungsten-arc spot welding to aluminum, including work-hardenable alloys.

PLATE WELDING

Development of Square-butt Technique

As now known, the welding of aluminum plate with the inert-gas consumable-electrode process normally calls for the preparation of beveled edges. Welding is carried out from one side and, after back chipping, from the other. Several stringer-bead passes on each side are ordinarily required to complete the joint. For example, ordinarily 1½-in. thick plate would be prepared with beveled edges and three passes would be made from each side at 4 ipm per pass. As presently practiced, the current for this operation would be limited to approximately 400 amp., because attempts to exceed this value would ordinarily result in an unstable arc, thereby resulting in severe oxide folds and porosity.

Investigators have realized that it would be possible to weld the heavy plate in fewer passes if the 400 amp. limit could be extended. Also, the additional input of heat would tend to reduce porosity, since any porosity-forming gas in the metal would bubble out of the weld before freezing occurred. Although many theories have been offered as to why the limit of 400 amp. could not be exceeded, attempts to reduce these theories to practice wherein the undesired effects could be eliminated have not proved particularly fruitful. Recently, however, it was possible to extend greatly the permissible current levels in aluminum welding. Although it is not clear to just what changes in the art this improvement in current range can be attributed, a number of forces appear to be at work simultaneously. These include improvements in gas purity, shielding, wire quality, and the introduction of slope-controlled constant-potential power supplies.

The use of higher welding-current levels during welding has made it possible to simplify greatly the preparation of plate edges. The welding operation is often carried out in one pass from each side, and at a much greater speed per pass than previously obtained. Back chipping is rarely required, and welding in one pass instead of several stringer-bead passes greatly reduces the total heat input. This reduction means less distortion and, in the case of heat-treatable alloys, it gives better as-welded properties.

This form of welding often utilizes a square-butt joint preparation and may sometimes be termed "square-butt welding." Perhaps, a more accurate term is simply "high-current welding."

Square-butt Welding Requirements

No matter how termed, the application of square-butt welding calls for a careful consideration of several factors. First, the torch—whether manual or mechanized—must be able to pass 80 to 100 cfh of argon without excessive turbulence. Next, the welding wire must be free of foreign material. Furthermore, the edges of sheared aluminum plate must be cleaned by the removal of surface metal in which grease from the shearing operation may have become imbedded. Both the surface condition of the welding wire and of the sheared edges of aluminum plate represent conditions to which too little attention may have been given in the past.

Figure 1 shows the importance of plate-or sheet-edge cleaning. As shown on the left half of the photo, the edges of each of two butted sheets were filed after shearing; the right halves were left as sheared. The top X-ray shows the results after the first pass. The center X-ray shows the results after back chipping and applying a second pass from the opposite side. The bottom view is the result after chipping out the first pass on the right side of the plates, and only then applying a new or third pass. It is obvious that the porosity must have been generated from imbedded dirt in the as-sheared edges. If the porosity had come from the welding wire, which incidentally was a random selection from commercial stock, or from improper shielding; there would be no reason to expect any reduction in porosity from pass 1 to pass 3.

The selection of appropriate power supplies constitutes another factor which is important in high-current welding. Recently developed constant-potential power supplies which incorporate slope control are beneficial in achieving the necessary higher welding current ranges. Actually, the introduction of slope control in a constant-potential power supply means a departure from true constant voltage in the direction of the conventional or drooping power supply. Considering this, it is not surprising to note that extremely good results have also been obtained with some conventional power supplies. However, in adapting present-day equipment to the higher currents, the operator is warned to reconsider the rating

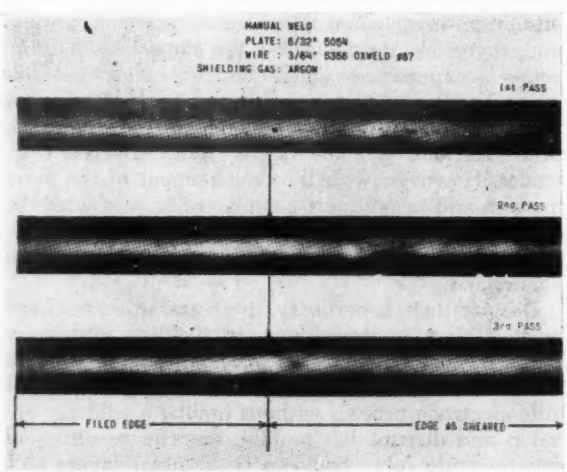


Figure 1. Effect of plate-edge cleaning.

of torch and welding machine since previous welding probably was carried out at considerably lower current values.

Ordinarily for plate up to about ⅝ in. thick, a square-butt joint prepared with tungsten-arc cutting or machined or filed after shearing will be adequate. Although over ⅝ in. thicknesses can be welded with a true square-butt joint, the amount of reinforcement may be regarded as excessive for some applications. Where reinforcement must be minimized or avoided, both sides of the joint may be veed to the amount required to provide space for the filler metal so that excess reinforcement is not produced. It should be borne in mind, however, that the degree of veeing required with this technique is considerably less than the normal conventional double-vee joint. The nose is quite thick and, in most cases, will represent about one-half the thickness of the plate. The joint preparation is not critical and, therefore, does not have to be machined to the same degree of accuracy as the conventional joints. Furthermore, the expense of back chipping is eliminated. The cost of removing the excess metal produced with the square-butt joint should be balanced against the cost of preparing the edges, etc.

Results

View C in Figure 2 shows a cross section of a typical square-butt weld prepared in ½-in. thick aluminum plate. In this case, the joint was a true square butt, and no beveling was utilized to reduce weld reinforcement. This weld was made with argon shielding. In Figure 2, View D also shows another weld with the same joint preparation and argon shielding. In this case, the weld was made with one pass from one side into a backup which was later machined off. View E of Figure 2 shows a weld made with 75 per cent helium and 25 per cent argon, again using the same joint preparation as the previous two. View B of Figure 2 shows the cross section of a weld made with conventional stringer-bead passes. In this case, five stringers were utilized, and the joint was a conventional single-vee bevel.

When investigating the physical properties of welds prepared with the square-butt technique, it was decided to prepare butt joints in ½-in. thick 5356 aluminum plate. The variables to be evaluated were as follows: (1) argon and argon-helium mixtures, (2) single and double passes and (3) manual and mechanized welding. Also, samples were made with the stringer-bead technique and a single-vee joint preparation, to compare with square-butt joints. The results of these tests are summarized in Figure 3. It will be noted that the ultimate tensile strength, the elongation, and bend-test results do not vary widely from one method to another. The somewhat lower ductilities, which are accompanied by slightly higher ultimate strengths, can possibly be attributed to higher welding speeds. It will also be noted that the majority of samples passed a 4 T bend and that all would pass a 6⅔ T-bend test. In those cases where all welding was from one side, the root-bend tests were used. The standard under MIL-E-0016053F (ships) is 6⅔ T. Therefore, the 4 T bend is well in excess of that required.

Test results indicated that equally sound welds may be obtained with either conventional methods or the square-butt technique. However, it can be readily seen that the square-butt technique holds a considerable economic advantage over the stringer-bead technique. Savings associated with the square-butt technique are particularly noticeable when results obtained with the 75 per cent helium and 25 per cent argon mixture are compared to results obtained with 100 per cent argon. Gas consumption is greatly reduced in the case of the square-butt technique when using argon. Welding time is also greatly reduced while wire consumption with the square-butt tech-

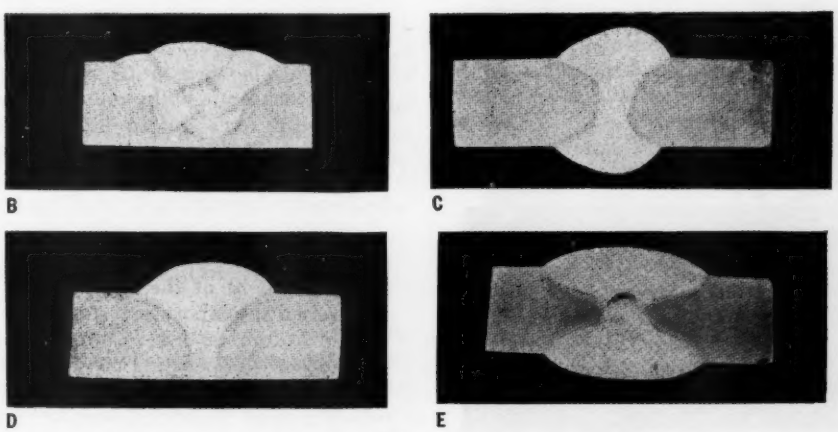


Figure 2. Typical square-butt and conventional welds in ½-in. thick 5356 aluminum plate as made with inert-gas consumable-electrode process. (Views B, C, D and E correspond to welds B, C, D and E in Figure 3.)

		A	B	C	D	E	F
	TYPE JOINT NO. OF PASSES	7	6	2	1	2	2
TECHNIQUE OR PROCEDURE	OPERATION	MECHANIZED	MECHANIZED	MECHANIZED	MECHANIZED	MECHANIZED	MANUAL
	WELDING WIRE	1/16" 5356	1/16" 5356	3/32" 5356	3/32" 5356	3/32" 5356	1/16" 5356
	SHIELDING GAS	75% HELIUM*	ARGON	ARGON	ARGON	75% HELIUM*	ARGON
PHYSICAL DATA	ULTIMATE TENSIL STRENGTH (P.S.I.)	42,200	42,900	43,200	41,100	40,900	43,500
	ELONG. IN 2 INCHES	12.5%	13.5%	11.0%	13.0%	14.0%	14.5%
	BEND RESULTS (NOTE THAT STANDARD IS 6-2/3 T)	3 OF 3 PASSED 4T; 4 OF 4 PASSED 6-2/3T.	3 OF 3 PASSED 4T; 1 OF 1 PASSED 6-2/3T	0 OF 4 PASSED 4T; 1 OF 1 PASSED 6-2/3T.	3 OF 3 PASSED 4T TEST	3 OF 4 PASSED 4T TEST	3 OF 3 PASSED 4T TEST
COST FACTORS	SHIELDING GAS (CU.FT./FOOT OF WELD)	7.9	2.7	1.4	1.3	4.1	1.4
	ARC TIME (MIN./FOOT OF WELD)	3.8	3.3	1.0	1.0	1.4	1.7
	WELDING WIRE (LB./FOOT OF WELD)	0.24	0.23	0.13	0.14	0.16	0.16

* BALANCE ARGON

Figure 3. Comparison of physical test results and cost factors for inert-gas consumable-electrode welds in ½-in. thick 5356 aluminum plate.

nique is only approximately one-half that utilized in the stringer-bead technique.

Square-butt welding offers considerable advantages from an economic standpoint and compares favorably with other techniques with respect to physical properties. However, weldment buildup may be regarded as excessive for some applications or code requirements. Earlier it was stated that a modification of the true square-butt preparation is made sometimes for the purpose of reducing weld reinforcement. This amounts to a simple mathematical calculation to determine, at a given progression speed, how much wire is being burned off and how much space is required to absorb it. For example, Figure 4 shows a weld in which one side was veed approximately one-third of the plate thickness in order to absorb the filler metal; the lower side was left as a normal square-butt joint preparation. It should be pointed out, however, in examining Figure 4 that no effort was made to obtain the maximum penetration which is possible with the technique. This weld was prepared merely for the purpose of demonstrating the ability to obtain and control any degree of weld reinforcement.

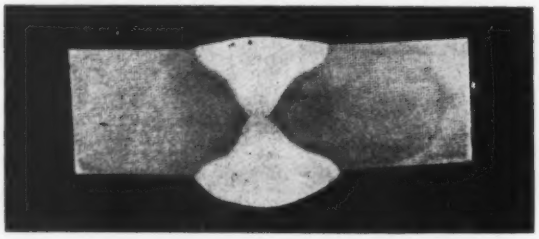


Figure 4. Reduced weld build-up resulting from modification of square-butt technique.

In introducing the square-butt or high-current technique for some applications, the observation was made that reasonably good alignment of the two opposing passes would be required in order to be certain that complete fusion between the roots of the two passes would be obtained. Here is another case where beveling helps to solve the problem. In cases where beveling is not needed for control of buildup, a very slight bevel can be placed on the edges to serve as a lineup for the operator so that he may be certain he is squarely over the joint at all times.

Most welds made with the square-butt or high-current technique will yield a water-clear X-ray picture well in excess of any of the standard X-ray requirements. Even when a particular weld is not found to be water-clear, the amount of porosity present will be found to be extremely small and widely scattered.

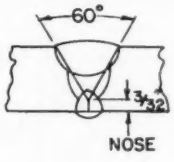
Field Applications

Development of the new high-current technique has passed the laboratory stage and is now in active use for a number of field applications in general accordance with operating conditions shown in Figure 5 and Table I. The first of these is shown in Figure 6 where a large cylindrical section of an off-shore drilling rig is being fabricated. In this operation, a square-butt weld is made from one side, utilizing a

TABLE I—*Mechanized "Square-butt" Welding Conditions*

Plate thickness, in.	Type of joint	Edge preparation	Wire diameter, in.	Shielding gas, argon, cfh	No. of passes	Welding speed, ipm	Current, amp DCRP	Voltage, v	Approximate wire-feed speed, ipm
¼	*Square butt	Tungsten-arc cut or sheared with edges filed	3/32	80	1	23	370	24	170
¼	*Square butt	Same as above	1/16	60	2	35	280	23-24	240
⅜	*Square butt	Same as above	3/32	80	1	18	420	24-25	200
⅜	*Square butt	Same as above	3/32	80	2	28-30	350	24-25	155
½	*Square butt	Same as above	3/32 or ⅛	100	1	14-15	450	25	3/32 wire-210 1/8 wire-125
½	*Square butt	Same as above	3/32	80	2	23	430	25	205
⅝	*Square butt	Same as above	3/32	80	2	18	430	25	205
¾	*Square butt	Same as above	3/32 or ⅛	100	2	16	450	25-26	3/32 wire-210 1/8 wire-125
1	*Square butt	Same as above	3/32 or ⅛	100	2	10-12	500	25-26	3/32 wire-240 1/8 wire-135
1¼	*Square butt	Same as above	1/8	100	2	8-10	550	26	145
1½	*Square butt	Tungsten-arc cut or sheared with edges filed	9/64	100	2	8	590	26	130

* Note: A variation of this high-current density technique may be employed whereby weld reinforcement is reduced to a minimum through the use of a joint design consisting of grooved or beveled plate edges. Under such conditions, welding procedures will be the same, with perhaps somewhat higher travel speeds and lower currents than shown above,



MADE WITH 50 CFH ARGON AND 1/16-IN. DIAMETER 5356 FILLER WIRE

POSITION	TENSILE STRENGTH*	ELONGATION IN 2 INCHES*
VERTICAL	41,200 PSI	12.9%
OVERHEAD	40,400 PSI	13.0%
HORIZONTAL	41,500 PSI	13.3%

*AVERAGE PHYSICAL BASED ON THREE TEST FROM EACH OF THREE WELDS.

Figure 5. Manual butt welds in ½-in. thick 5456 H321 plate.

U-groove backup. The material is 0.387-in. thick 5083 aluminum. Welding for this application was carried out at approximately 16 ipm with 24 v and 400 amp., d-c reversed polarity, and with 3/32-in. diameter 5183 aluminum wire. No material preparation other than squaring the edges was made, and no back-chipping or post-dressing was employed. The shielding-gas flow was approximately 80 cfh of argon. Figure 7 illustrates the sections joined together to form the finished structure.

WELDING WITH SMALL-DIAMETER WIRE

Past Limitations

As orginally reported three years ago, welding with the inert-gas consumable-electrode process and small diameter wires was limited primarily to thin-gage stainless and carbon steels.* Since that time, however, the consumable electrode process has been extended to include aluminum alloys, with which it is frequently desirable to weld with small-diameter wires.

Essentially, what had been learned in developing the small-diameter wire system for carbon and stainless steels can be applied to aluminum. The difficulty with aluminum, however, was mainly mechanical and involved developing a way to pull or push a small-diameter wire in a consistent manner.

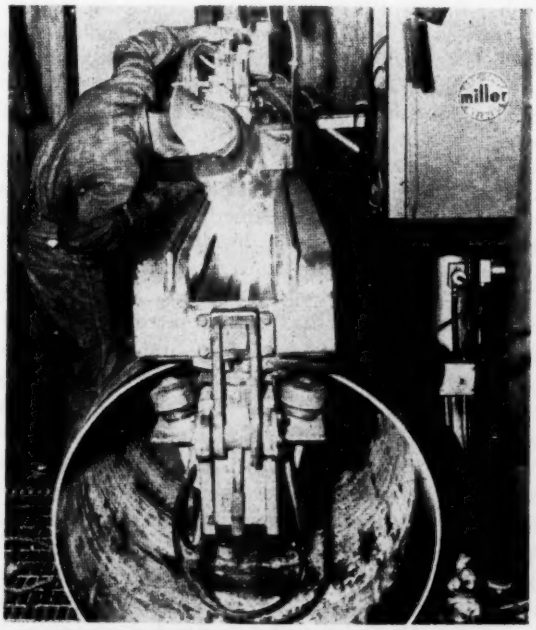


Figure 6. Application of square-butt technique for fabrication of tubular aluminum leg section of off-shore oil-drilling rig.

*Richter, K. E., and Essig, J. F. M., "Consumable-Electrode Inert-Gas Welding with Small Diameter Wires," presented at the 1956 AWS National Fall Meeting in Cleveland, Ohio, October 8-12.

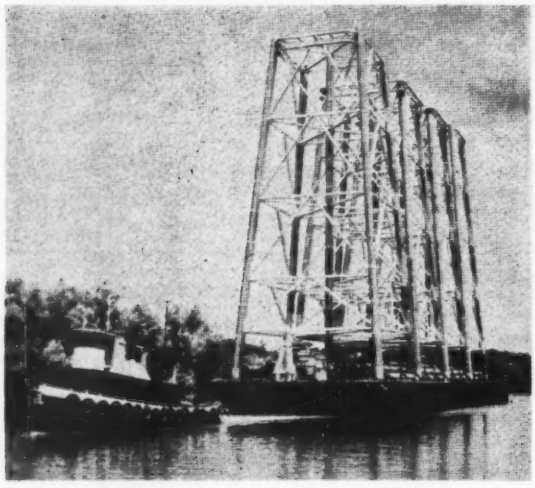


Figure 7. Welded off-shore oil-drilling rig being towed to sea.

Equipment

Suitable equipment has now been developed in the form of spool-on-gun torches and also kits to adapt standard inert-gas consumable-electrode process equipment so that wire as small as 0.030 in. diam. may be easily pushed through a 10-ft. conduit to the welding torch. The welding wire is carried with the gun and the driving means is contained within the gun. The pull-and-push methods should not be considered directly interchangeable. The kit is intended primarily where the user already has existing inert-gas consumable-electrode equipment and wishes to adapt it at a minimum cost both in terms of conversion and in operation. The spool-on-gun torch is intended primarily for portability wherein a few welds may be at one posititon before the operator is obliged to move a considerable distance to make his next welds. Obviously, the wire on these spools will be expensive. Furthermore, because of the driving system employed, weld quality cannot be expected to equal that obtained with a kit, since the spool-on-gun drive system does not have the degree of regulation possible with standard equipment. Therefore, the spool-on-gun should be considered solely on the basis of the need for extreme portability wherein weld quality is not of the first consideration.

The conversion system, or the system in which the wire is pushed through the welding conduit to the gun, utilizes either conventional or slope-controlled constant-potential power. Further, it may be operated with either a spray-type or short arc. The spool-on-gun unit, on the other hand, is intended solely for operation with conventional power and only with a spray-type arc. It is not suitable for short arcs. The ability of the conversion kit to utilize either the short or spray-arc technique offers a decided advantage in that the spray-arc type can be used on material of greater thickness with ease but on extremely thin materials only with difficulty. Further, the short-arc technique lends itself to all-position welding on a given joint without readjustment of the equipment. The short-arc technique also permits higher speeds and easier control of the weld puddle.

Process Features

Small-wire welding with the inert-gas consumable-electrode process has reached the point where it can be considered a new way of welding for both manual and mechanized applications. It represents a new tool for both small and large shops. Use of the short-arc technique in particular permits a high degree of control to be obtained on thin aluminum sheet with a minimum of training time. Often it can be used profitably as an alternative to tungsten-arc welding.

A significant feature in the small-wire technique is shown in Figure 8, which illustrates the burn-off rate in pounds per hour for various current settings at different voltages, arc voltages, or arc lengths. The relationship shown in these curves is not unique.

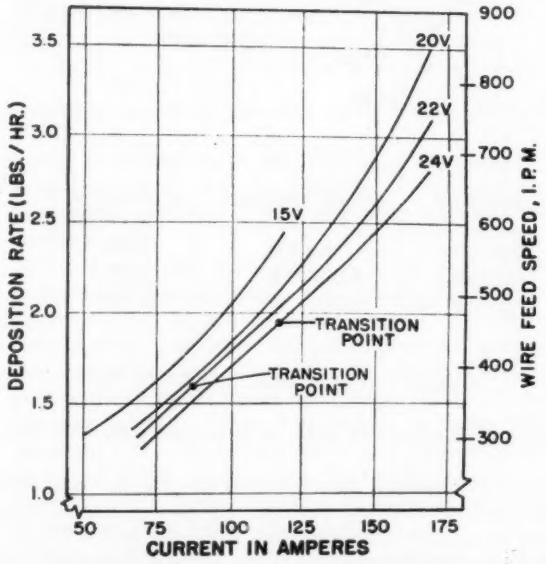


Figure 8. Metal-deposition rates for 0.030-in. diameter 4043 aluminum wire. ("Transition point" indicates change from globular to spray type of metal transfer with decrease in current.)

However, this illustration shows a far greater voltage range than one would ordinarily experience. In the past, the difference in burn-off at a given current between a 20-v and a 24-v arc was not considered of great significance. However, the difference in wire burn-off becomes significant when relatively low short-arc voltages are considered. For example, at 115 amp. for a 15-v arc and a 24-v arc, the respective rates are 2.3 and 1.9 lb. per hr., or a 21 per cent increase in burn-off by changing from a spray arc to a short arc.

SPOT WELDING

Inert-gas Consumable-electrode Process

The inert-gas consumable-electrode spot-welding process was introduced commercially in 1954. At that time it was intended primarily for use on carbon steel, stainless steel, and some copper-bearing alloys. The process was not recommended for aluminum because of some difficulty in obtaining consistent starts, which are essential if uniformly good results are to be expected. Subsequent work with results as shown in Table II developed the fact that, for a given wire,

TABLE II—*Inert-gas Consumable-electrode Spot-welding Starting Requirements*

Aluminum alloy, 1/16-in. diam. filler wire	Volts	Minimum current, amp.
1100	25	180
	28	200
4043	24-27	130
5154	24	360
	28	400
5356	24	400
	28	250

there was a voltage and current range within which reasonably good starting can be obtained. Obviously, however, every job or application may not fit into this given range due to the particular thickness of the material or other considerations. The process is still somewhat limited in that, when joining sheets of equal thicknesses, it may be found difficult to control penetration so that excessive underbead formation does not occur. On the other hand, in joining a thin section to a relatively heavy section, this process limitation does not occur. An example is a mitered joint made with inert-gas consumable-electrode spot welding for use on storm doors or windows. In this case, a square block of aluminum is inserted inside the joint to form a heavy section. The spot welds are then made, and the excess metal is quickly removed with a standard rivet flusher commonly used in the aircraft industry.

Use of the inert-gas consumable-electrode spot-welding process for plug welding of aluminum has normally been limited to a maximum of 3/16-in. thick material. This is due to the tendency of cold laps to develop at the bottom of plug holes. To some extent, the use of argon-helium mixtures, in preference to argon only, tended to reduce this tendency although it did not represent a complete solution. By modifying the normal joint design, however, consistently good results have been obtained on up to ¼-in. thick material with complete freedom from cold laps.

Reference to Figure 9 will show the preferred joint design for joining ¼-in. thick plate to an aluminum casting. This new joint design tends to move the heat sink away from the interfaces of the joint, thereby permitting complete fusion to occur at this point.

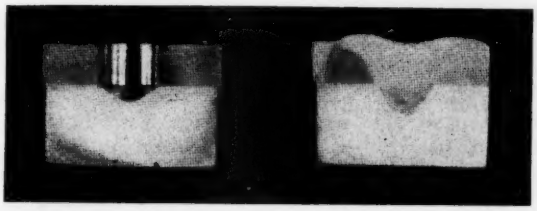


Figure 9. Cross section of plug-weld joint preparation and completed weld.

Tungsten-arc Developments

Unlike past experience with the inert-gas consumable-electrode spot welding, the tungsten-arc process offers reasonably good starting characteristics. Actually, investigation of spot welding aluminum with the tungsten-arc process preceded development of the consumable-electrode process by some four or five years. However, difficulties were experienced in obtaining consistently satisfactory weld nuggets. This led to development of the consumable-electrode process as a solution to the difficulty. As has been pointed out, however, only a limited degree of success was obtained. Therefore, it was decided to reinvestigate the tungsten-arc process, because it is relatively free from starting difficulties, and because further improvements in starting techniques had been made. This new program subsequently produced results as shown in Figure 10. As may be seen, consistently good tungsten-arc spot welds on aluminum can be obtained on sheet thickness up to about 0.090-0.100 in. In the case of heat-treatable alloys, however, complete freedom of cracking cannot always be obtained with the most elementary form of the process.

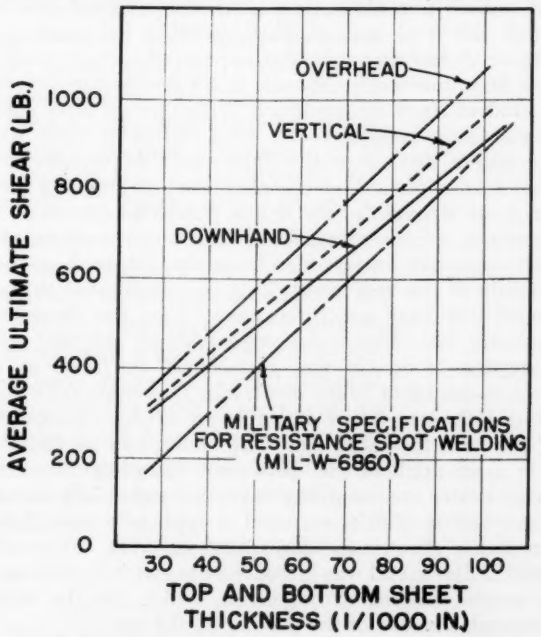


Figure 10. Results obtained with tungsten-arc spot welding on 1100 aluminum sheet.

TABLE III—*Inert-gas Metal-arc Spot-welding Process Selection Chart*

Bottom sheet thickness, in.	Top sheet thickness, in. 1/32	1/16	3/32	1/8	5/32	3/16	1/4
1/32	TA						
1/16	TA	TA MAB					
3/32	TA MA	TA MAB	TA MAB P				
1/8	TA MA	TA MA	TA MAB P	TA MAB P			
5/32	TA MA	TA MA	TA MA MAB	MAB P	MAB P		
3/16	TA MA	TA MA	TA MA	MA P	MA P	P	
1/4	TA MA	TA MA	TA MA	MA P	MA P	P	P

Process designation: TA—Gas-shielded tungsten-arc welding. MA—Gas-shielded metal-arc welding. MAB—Gas-shielded metal-arc welding with weld back-up. P—Gas-shielded metal-arc plug weld.

In re-examining tungsten-arc spot welding of aluminum, it was reasoned that the lack of consistent penetration and poor nugget cross section was associated with the use of alternating-current welding power. Since it is known that d-c straight polarity produces more consistent and deeper penetration, it was decided to use this in preference to alternating current. However, the use of d-c straight polarity does not ordinarily produce very satisfactory results, since no cleaning action is afforded. Therefore, the material must be chemically cleaned before being spot welded. Furthermore, the chemically clean material must be spot welded using argon which is 99.995 per cent pure, or the weld surface will contain oxide folds. A tri-sodium-phosphate detergent was selected as the most practical and simplest solution for cleaning. Materials having an average amount of surface oxides can be immersed for 20 min. in solutions of this compound at room temperature. When rinsed with cold water they emerge clean. In a normally clean atmosphere, this material will be weldable for approximately five days after cleaning without showing loss in shear strength of the welds. Using this method of cleaning, consistent shear strength could be obtained, but excessive crater of indentation occurred in the middle of the spot weld. This was attributed to the extremely high arc force exerted by the straight-polarity arc. The usual procedure of pointing the tungsten electrode was abandoned in favor of a square-ended or blunt electrode. This materially reduced the arc force, and a ⅛ or 5/32-in. diameter 2 per cent thoriated electrode was found preferable for most applications. However, complete freedom from crater cracking was not found possible without the addition of filler material in applications on heat-treatable aluminum alloys such as 2014, 2024 and 6061. Filler metal was introduced in rod form through a special feeding arrangement, which fed the wire through the side of the gas cup to the arc.

A further advance was realized by the use of a new patented starting technique known as pilot arc. In essence, a similarity can be drawn between a pilot arc and the small pilot flame in a gas stove which serves the purpose of igniting the main burner as desired. In this case, a small straight-polarity arc of approximately 5 amp. exists continuously between the electrode and cup. This arc supplies an ionized path between the electrode and the work and keeps the electrode in an incandescent state so that the application of welding voltage across the electrode and work results in instantaneous starting. A further benefit is obtained from the pilot arc. Since the welding electrode is maintained in a state of incandescence, it is also thermally stable. As a result, the arc gap is maintained constant. In high-frequency starting, several starts are generally made on a scrap piece of material to bring the tungsten electrode up to heat and to establish a constant arc gap. However, the use of pilot-arc starting means that the first spot will be as good as the last. Figure 11 shows a typical pilot-arc circuit.

Process Selection

The choice of whether to spot weld aluminum with either the inert-gas consumable-electrode or nonconsumable-electrode process can be determined to some degree by answering the following questions. Can the material be cleaned chemically, and is it economical to do so? Will the fit-up be good? Is it a heat-

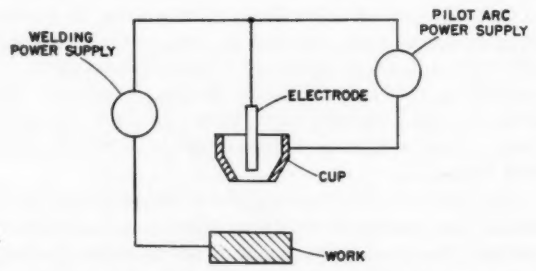


Figure 11. Schematic of pilot-arc circuit used in tungsten-arc spot welding.

treatable alloy? How thick are the members to be joined? If fit-up is poor, if the material cannot be cleaned chemically, if it is quite thick, or if it is a heat-treatable alloy, the consumable-electrode process is generally to be preferred. However, if a higher degree of shear-strength consistency is demanded and the application will bear the expense of cleaning and good fit-up, the nonconsumable-electrode or tungsten-arc process will generally be preferred. The tungsten-arc process can also be used on the heat-treatable aluminum alloys although the consumable-electrode process should be investigated first since cold-rod addition adds equipment complexities. In considering limitations of the various processes in regard to sheet thicknesses, reference may be made to Table III which shows the process preferred for each sheet thickness combination up to ¼ of an inch. In those cases where two processes are recommended, the process listed first is preferred.

Conclusion

Two significant points stand out as a result of recent developments in the welding of aluminum. First, the inert-gas consumable-electrode process may be utilized to weld very thin or thick material with equal ease. Second, both the inert-gas consumable-electrode and tungsten-arc processes may be used for spot welding, wherein any choice between the two depends upon requirements of the particular application which is involved.

The inert-gas metal-arc processes have been developed to the point where they can be economically and readily applied to any aluminum-fabrication problem. Furthermore, application of the inert-gas metal-arc processes in aluminum fabrication can be expected to result in greater economies, improved quality, simplicity of operation and a wider range of fabrication possibilities through the expansion of existing welding methods. Thus, aluminum fabricated by means of welding can be expected to find more and more use as a structural material for the aircraft and missile industries and for items such as bridge spans and pressure vessels.

Advanced reactor studies have been completed by contractors to the AEC to determine significant engineering advances which could be incorporated in power plants which could begin construction in 1960. Three of these studies were centered about the Pressurized Water Reactor (PWR), the Boiling Water Reactor (BWR), and the Organic Moderated Reactor (OMR). The studies showed possible increases in thermal efficiencies of all three types. Increases in steam pressures were largely responsible for the improved performance expected from PWR and OMR. In the BWR, increased efficiency resulted from better heat recovery in the feed system and improved turbine design. A second major achievement in all three studies was that gained by improved core design techniques which provide a larger heat release rate from cores limited in size by feasible reactor vessel dimensions. Somewhat higher fuel enrichment is characteristic of the advanced designs. No major changes have been made in the heat removal design and equipment. The net station output per reactor is increased by about 65 percent for both the PWR and the BWR over the Yankee and Dresden plants. In the case of the OMR, no comparison with a full scale, presently designed plant can be made, since the only existing organic reactor is a relatively small experimental installation.

—from NUCLEONICS
August, 1959

Nuclear powered, POLARIS missile-packing submarines are now being built faster than post-war diesel models.

A new 16-month construction record went on the books on 22 September 1959 when General Dynamics Corporation's Electric Boat Division launched the PATRICK HENRY.

In building the Navy's second Fleet Ballistic Missile sub, the Groton shipbuilders succeeded in knocking two months off their best keel laying-to-launching period for conventional submarines since the war. In readying the PATRICK HENRY for its maiden splash they even bettered the 18 months needed to launch the pioneer A-sub NAUTILUS and the first Polaris ship, GEORGE WASHINGTON.

A crowd of 20,000 attended the noontime launching ceremonies which featured an address by Secretary of Labor James P. Mitchell. Mrs. Leslie C. Arends, wife of the Illinois congressman, christened the 380-foot, 5,400-ton floating underwater missile base.

In addition to Secretary Mitchell, other speakers included Vice Admiral Thomas S. Combs, USN, Commander, Eastern Sea Frontier in New York, and Earl Dallam Johnson, president of General Dynamics.

Commander Harold E. Shear, holder of the Silver Star Medal for World War II submarine patrols, is the new sub's prospective commanding officer. A native of New York City and a 1941 graduate of the Naval Academy, he has spent the past year receiving special training in nuclear propulsion, missiles, fire control and navigation.

The PATRICK HENRY is the seventh atomic submarine launched by General Dynamics. The shipyard inaugurated the nuclear era in 1954 with the NAUTILUS launching and has followed with five other prototype ships. The PATRIC KHENRY is the first atomic sister ship launched at the yard.

—from a General Dynamics Corp. news release
dated 16 September 1959

A plan for the installation of a nuclear reactor for the propulsion of an existing tanker hull has been announced by a Dutch organization of ship owners, ship builders and technical institutions. The present plan succeeds an early proposal to construct a new nuclear powered tanker which has been deferred on account of high costs. It is proposed to adapt a turbo-electric driven tanker of about 18,000 DWT to nuclear power by the installation of a 4,000 to 4,500 SHP nuclear reactor. Such a reactor, with its shielding, is estimated to weigh about 1,100 tons. It would be located in a centerline tank slightly aft of amidships with the turbo-generator auxiliaries and control equipment in adjacent wing tanks. The reactor, a pressurized water type, would be located in a pressure vessel about 33 feet high and 27 feet in diameter. Throttle steam conditions are 330 psia saturated.

—from THE INSTITUTE OF MARINE ENGINEERS
June 1959

Claude S. Gillette

On 27 September 1959, death claimed Rear Admiral Claude Sexton Gillette, U.S. Navy, Retired. This occurred suddenly in Blackville, Province of New Brunswick, Canada.

Admiral Gillette joined the Society in 1916 and was elected Secretary-Treasurer for 1935 and 1936. He served in this office until detached from duty in Washington on 1 June 1936. Just prior to his election, the Navy drastically changed its security rules so that his task of editing the JOURNAL was made somewhat more difficult by having to find copy to replace that which the new rules denied to the JOURNAL.

Admiral Gillette graduated from the Naval Academy in the Class of 1909 and was among the early group which was selected for Engineering Duty Only when the 1916 Act was put into effect after World War I. For his service in World War I, he was awarded a Special Letter of Commendation.

Between the wars Admiral Gillette served in the Design Division of the Bureau of Engineering, as Officer in Charge of the Naval Boiler Factory, Philadelphia Navy Yard and as Manager of the Pearl Harbor Navy Yard. He was in this last position when the Japanese attack occurred on 7 December 1941 and directed the dramatic salvage and repair work on the damaged ships which resulted in the early return to active fleet service of most of them.

Some of these ships were returned to the mainland for more complete repairs and here, Admiral Gillette, after six months of duty in the Bureau of Ships, completed the repair job as Manager of the Puget Sound Navy Yard at Bremerton, Washington.

Following his Puget Sound duty, he became Supervisor of Shipbuilding at Groton, Connecticut, where he was serving when he retired from active duty on 1 August 1946.

After retirement Admiral Gillette made his home in Bath, Maine where funeral services were held on 30 September with interment in Oak Grove Cemetery at Bath.

Admiral Gillette is survived by his wife, Lydia Baxter Gillette whose address is 1111 Washington St., Bath, Maine.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society announces with pleasure that the following have joined its ranks since the publication of the August, 1959 issue of the JOURNAL:

NAVAL

Clark, James Mansfield, LTJG, USN
Mail: 359 Davidson Drive, Idaho Falls, Idaho

Gatje, George Carlisle, LT, USN
Mail: Naval Nuclear Power Training Unit (A1W)
National Reactor Test Station, Idaho Falls, Idaho

Jones, John Hunt, LTJG, USN
Mail: 10 Hillside Road, Levittown, Penna.

McClain, Warren Howard, CAPT, USN
Assistant Industrial Manager, USN and Supervisor of Shipbuilding, USN and Naval Inspector of Ordnance, Seattle, Washington
Mail: 2400—11th Avenue, S. W., Seattle 4, Washington

Parham, John C., RADM, USN (Ret)
Manager, Washington Office, Military Division, Motorola, Inc. 1145—19th Street, N. W., Suite 606, Washington 6, D. C.

Russell, Robert E., LTJG, USN (Ret)
Representative, Sperry Gyroscope Co.
Mail: Mail Station T-203, Sperry Gyroscope Co., Great Neck, N. Y.

CIVIL

Lund, Theodore J.
Marine Engineer, Navy Department, Washington 25, D. C.
Mail: 509 Quaint Acres Drive, Silver Spring, Md.

Nahin, Wallace Lou
Vice President, Waukesha Bearings Corp.
Mail: 9601 Bulls Run Parkway, Bethesda 14, Md.

West, William K.
Sales Manager, Defense Products, Delco Products Division, General Motors Corp., 329 East First Street, Dayton, Ohio

ASSOCIATE

Crooks, Harry Augustine
Submarine Market Manager, Exide Industrial Div., The Electric Storage Battery Co., P.O. Box 5723, Philadelphia 20, Penna.

Flaschar, W. O., First Lt., USAR (Inactive)
Applications Engineer, Solar Aircraft Co.
618 Cafritz Bldg., 1625 Eye Street, N. W., Washington 6, D. C.

Nierzwicki, Carl P.
Washington Representative, Motorola, Inc., 1145—19th Street, N. W., Suite 606, Washington 6, D. C.

TRANSFERRED—ASSOCIATE TO NAVAL

Barnard, Edward K., LTJG, USNR

RESIGNATIONS

Ayers, Kenneth A., CAPT., USNR ..... Naval
Gibson, Arthur F. ..... Associate
Harman, William H., Jr. ..... Associate
Hollatz, Carl J. ..... Associate
Lewis, Paul O. Civil
Stringham, Warde Barlow ..... Associate
Waples, Robert M. Civil

DEATHS

Buchi, Alfred J. Dr. Civil
Davey, John J. Civil
Ewen, Edward Coyle, VADM, USN (Ret) ..... Naval
Farrell, Lawrence Joseph, LTJG, USN ..... Naval
Fedrick, Jack Rowley, LT, USNR ..... Naval
Frisch, Martin Civil
Gilbert, Walter James Civil
Gillette, Claude S., RADM, USN (Ret) ..... Naval
Gleitz, Herbert Civil
Gray, Joseph Harry, LCDR, USNR ..... Naval
Harvey, Minor Civil
Hofer, James Vincent, LT, USNR ..... Naval
Reamy, Thomas Gordon, CAPT, USN (Ret) .... Naval
Sorenson, Hans P. ..... Associate

ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

Each author who is subject to the Security Regulations of the Department of Defense, is personally responsible for the clearance of an original article before submitting it to the Society for consideration. In forwarding manuscripts, a statement in this regard should be included.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 20 reprint copies of his article free of charge. Additional copies may be purchased from the Society *if the request is received 30 days prior to the publication date which is the 25th of the issue month.* Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which sufficient material is not already on hand.

ASSOCIATION NOTES

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

COPIES OF JOURNALS

The Society has made arrangements with the Johnson Reprint Corp. to be our sole representative for the sale of copies or reproductions of any Journals or parts of Journals which were printed prior to 1951. Any requests or inquiries which are received by the Society for these will be forwarded without any action by us.

When making inquiries as to the procurement of or orders for copies or portions of any Journal from Volume 1 (1889) through Volume 62 (1950) please address

Johnson Reprint Corp.
111 5th Avenue, New York, N.Y.

For Volume 63 (1951) and later address the Society.

PERMISSION TO REPRINT

All material published in the JOURNAL, except the articles which are prefaced with an "Acknowledgement," are copyrighted by the American Society of Naval Engineers.

Permission is granted to reprint any copyrighted material contained herein if the following conditions are met:

a) The article is reprinted in full. Extracts or summaries or condensations may be printed with the consent of the author.

b) Credit is given to the JOURNAL with reference to the issue.

c) Credit is given to the author.

d) If the author is a military officer or a civilian employee of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal opinions of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

APPLICATION FOR MEMBERSHIP

IN THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

(See reverse side for required qualifications for various classes of membership)

Date _____

I, _____ hereby apply for membership in the American Society of Naval Engineers, Inc., and enclose $10.00 as my annual membership dues for the year _____ $8.00 of which is for a subscription to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., for one year. I submit the following information:

For Naval Membership

Name _____
(First) (Middle) (Last)

Rank _____ File No. _____

Business connection and position, if any _____

For Civil Membership

Name _____
(First) (Middle) (Last)

Years in engineering work _____

Years in responsible charge of important work _____

Present business connection and position _____

Recommended by (two members) _____

_____

For Associate Membership

Name _____
(First) (Middle) (Last)

Rank, if Commissioned Officer of U.S. Army or of foreign military or Naval service _____

Business connection and position _____

Recommended by (one member) _____

_____
Signature of Applicant

Address for JOURNAL and Mail

_____

_____

MAIL TO SECRETARY-TREASURER
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
Suite 403, Continental Building
1012 14th St., N.W. Washington 5, D.C.

Company Memberships Not Available

QUALIFICATION FOR MEMBERSHIP

Commissioned and ex-commissioned officers, warrant and ex-warrant officers, and reserve (commissioned and warrant) officers of the Navy, Coast Guard and Marine Corps, of the United States, active or retired, shall be eligible as Naval Members. Persons eligible as Naval Members shall be admitted upon application and payment of annual dues.

Persons in civil life whose knowledge of engineering is such that they can cooperate with Naval engineers in the promotion of professional knowledge may be eligible as Civil Members. They shall have been in the active practice of an engineering profession for at least eight years and in responsible charge of important work for five years, and shall be qualified to design as well as to direct engineering work. Fulfilling the duties of a professor of engineering who is in charge of a department in a college or school of accepted standing shall be taken as an equivalent to an equal number of years of active practice. Graduation from a school of engineering of recognized standing shall be considered as equivalent to two years of active practice. Persons eligible as Civil Members may be admitted upon application and payment of annual dues, provided that the application is accompanied by the recommendation of two members and provided that the application shall receive the approval of a majority of the Council.

Persons in civil life who are not eligible for civil membership, but who are especially interested in naval matters or the merchant marine may be eligible as Associate Members. Commissioned officers of the United States Army, United States Air Force and of foreign military and naval services may be eligible as associate members. Persons eligible to associate membership may be admitted upon application and payment of annual dues, provided the application has the recommendation of a member and provided the application shall receive the approval of a majority of the Council, except that in the case of commissioned officers of the United States Army, of the United States Air Force, and of foreign naval and military services, the recommendation of a member will not be required.

Undergraduates at schools to be named by and under regulations to be issued by the Council shall be admitted as Junior Members at one-half the dues of regular members during their course and for one year following graduation, after which time junior membership will be terminated, the member to have the privilege of transferring to regular membership in the appropriate category.

Associate and Junior Members shall be entitled to all the privileges of other members except voting and holding office.

The annual dues shall be $10.00, payable on 1 January in advance, of which $8.00 shall be for subscription to the JOURNAL of the American Society of Naval Engineers, Inc., for one year.

COMPANY MEMBERSHIPS NOT AVAILABLE

V
1
4

N
O
V

5
9

XU

Secretaries of the

AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Captain J. E. Hamilton, U. S. Navy Retired, Secretary-Treasurer
Commander Charles N. Payne, U.S.N., Assistant Secretary-Treasurer

---

Past Secretaries

1889 *P. A. Engineer R. S. Griffin, U. S. Navy*
1890 *Assistant Engineer W. M. McFarland, U. S. Navy*
1891 *Assistant Engineer Emil Theiss, U. S. Navy*
1892-93 *P. A. Engineer W. M. McFarland, U. S. Navy*
1894-95 *P. A. Engineer R. S. Griffin, U. S. Navy*
1896-97 *P. A. Engineer F. C. Bieg, U. S. Navy*
1898 *P. A. Engineer W. M. McFarland, U. S. Navy*
1899 *Chief Engineer A. B. Willits, U. S. Navy*
1900 *Lt. Cmdr. A. B. Willits, U. S. Navy*
1901 *Lieutenant B. C. Bryan, U. S. Navy*
1902 *Lieutenant C. W. Dyson, U. S. Navy*
1903 *Lt. Cmdr. John R. Edwards, U. S. Navy*
1904 *Lieutenant M. E. Reed, U. S. Navy*
1905 *Lieutenant W. W. White, U. S. Navy*
1906 *Lieutenant C. K. Mallory, U. S. Navy*
1907-08 *Lt. Comdr. T. C. Fenton, U. S. Navy*
1908-10 Lieutenant H. C. Dinger, U. S. Navy
1911 *Commander U. T. Holmes, U. S. Navy*
1912 *Lieutenant John Halligan, U. S. Navy*
1912 *Lt. Comdr. E. L. Bennett, U. S. Navy*
1913 Lieutenant O. L. Cox, U. S. Navy
1914 Lt. Comdr. H. C. Dinger, U. S. Navy
1915-16 *Lieutenant A. T. Church, U. S. Navy*
1917 Lt. Comdr. J. O. Richardson, U. S. Navy
1917-19 *Lt. Comdr. F. W. Sterling, U. S. Navy*
1919-21 Commander J. S. Evans, U. S. Navy
1921-23 Commander S. M. Robinson, U. S. Navy
1924-25 Commander Bryson Bruce, U. S. Navy
1926 Commander A. M. Charlton, U. S. Navy
1927-28 Commander H. B. Hird, U. S. Navy
1928 Captain O. L. Cox, U. S. Navy
1929-30 *Commander H. T. Smith, U. S. Navy*
1931 Captain O. L. Cox, U. S. Navy
1932 Commander H. F. D. Davis, U. S. Navy
1933-34 Commander H. B. Hird, U. S. Navy
1935-36 *Commander C. S. Gillette, U. S. Navy*
1936-38 Commander Roger W. Paine, U. S. Navy
1938-40 Lt. Comdr. Guy Chadwick, U. S. Navy
1940-44 Captain J. E. Hamilton, U. S. Navy
1945 Commander R. T. Sutherland, Jr., U. S. Navy
1945-48 Captain F. W. Walton, U. S. Navy
1948-51 Captain J. E. Hamilton, U. S. Navy

Past Assistant Secretaries

1939-40 Lieutenant Milo B. Williams (C.C.) U. S. Navy
1941-44 Lt. Comdr. Robert T. Sutherland, Jr., U.S. Navy
1945 Captain F. W. Walton, U.S. Navy
1945-47 Commander Floyd B. Schultz, U.S. Navy
1947-49 Commander C. H. Meigs, U. S. Navy
1949-50 Commander Frank C. Jones, U. S. Navy
1951-59 Captain Robert B. Madden, U.S.N.

Clerk and Administrative Assistant

1908-58 Mr. Arthur G. Fessenden
1958- Miss Ruth M. Leonard

---

*Names in italics deceased

NOVEMBER, 1959

TABLE OF CONTENTS

		PAGE
SECRETARY'S NOTES		583
Costs and Risks of ENGINEERING PROGRESS	SONENSHEIN	589
Deposits and Corrosion	Reprint	599
Transportation by Hydrofoil Boats	VonSCHERTEL-HOERNER	603
Special Purpose Propulsion	TAGGART	615
Development Program for Hydraulic Jets	TAGGART	623
Reduction Gear Machines	Reprint	633
Gay-Lussac Free Expansion Experiment	POTTER	643
High Performance Aircraft	Reprint	649
Thermoelectricity	COOPER & FRANKENBERGER	657
Transistors	Reprint	665
Basic Design Concepts	EVANS	671
The Project Manager	Reprint	679
Propeller and Rudder Reactions	KAFALI	685
Submerged Hydrofoils	NISHIYAMA	693
Discussion	SILVERSTEIN	700
Soviet Marine Engineering Notes	KASSELL	703
Naval Steam Turbine Construction	YOUNG	711
Missile Fire Protection	SEEGER & LAPP	719
Organic Reactor	Reprint	723
Platinum Resistance Thermometer	Reprint	729
Welding Aluminum	Reprint	735
DEPARTMENTS		744

V
1
4
N
O
V
9
5
XL